# NEWS & VIEWS

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*Dr. Robert L. Mikkelsen,*
*West Region Director*
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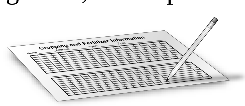
# Where Do Cations Fit in My Fertility Program?

**ALMOST** half of plant growth occurs underground. Since we don't see the roots, it is easy to underestimate the importance of the soil environment. To achieve high levels of production, close attention must be paid to soil conditions, including some of the seemingly less "glamorous" nutrients that are essential for plant growth.

Many of the soil cations are frequently overlooked when discussing the importance of balanced plant nutrition. Calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), and potassium ($K^{+}$) are usually called "basic cations" since they are highly dominant in more alkaline soils and do not cause acidity, compared with acid-forming cations such as aluminum ($Al^{3+}$) and hydrogen ($H^{+}$).

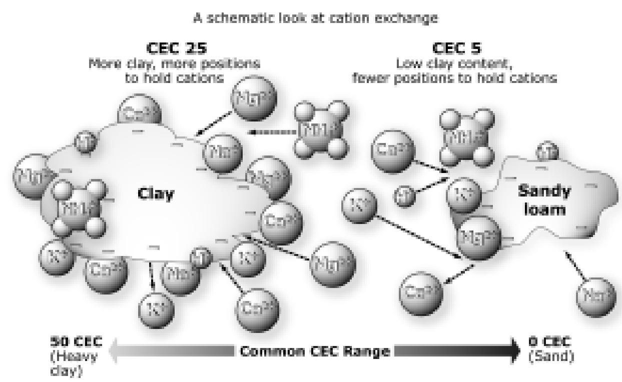
This brief review covers the function of Ca, Mg, and K in soil and plants. Since their concentrations and balance are essential in promoting healthy crop growth, it is important to understand their behavior.



## Calcium

Calcium is widely distributed in most Western soils. Even though Ca is commonly found in many rocks and minerals, this does not always assure an adequate supply of this element. Most plant-available Ca is held on the negatively charged sites in the soil, where it can be exchanged with other cations. This exchangeable Ca is the reserve that supplies plants with nutrients during the growing season. Plant nutrients must first be dissolved in the soil water bathing the roots before the plant can use them.

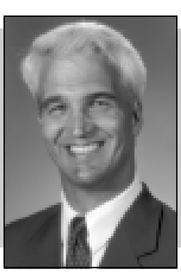
Calcium may also be present in solid forms that require dissolving before they become available for plant uptake. Lime and gypsum are two common minerals that contain Ca. Their solubility controls their availability to plants.




- **Lime** ($CaCO_3$) is frequently found in many Western soils, especially where the pH is above 7. Lime is also commonly added to acid soils since it will dissolve to form acid-neutralizing constituents and also provide a source of Ca. However, in neutral and alkaline soils, lime is very stable and will not rapidly dissolve. Adding lime in these conditions will do very little to improve nutrient availability and may even further reduce the solubility of phosphorus (P) and some micronutrients.

- **Gypsum** ($CaSO_4 \cdot 2H_2O$) is a naturally occurring mineral that is found in some Western soils or sometimes added as a soil amendment. Compared with lime, gypsum is relatively soluble in water, dissolving up to 2 g per liter of water releasing Ca and sulfate ($SO_4$) into solution without changing the soil pH. While gypsum can be an excellent Ca source, its solubility may not be sufficiently rapid to meet crop needs during peak demand period for some crops, such as during rapid cell division and fruit expansion.

Gypsum improves soil physical properties only in limited conditions. Where sodium (Na) exceeds 10 to 15% of the soil cation exchange capacity (CEC), additions of gypsum can reduce dispersion, restore aggregation, and enhance physical properties. The use of gypsum in non-sodic soils will not correct problems with soil physical properties such as compaction, root penetration, or water infiltration, except in specialized conditions.



Agronomic market development information provided by:
**Dr. Robert L. Mikkelsen, West Director**
**Potash & Phosphate Institute (PPI)**
**617 Oeste Drive, Davis, CA 95616**
**Phone: (530) 758-4237**
**E-mail: rmikkelsen@ppi-far.org**
**Website: www.ppi-ppic.org/west**

Even though adequate Ca may be present in soil, some plants have a high Ca requirement during peak growth periods, resulting in irreversible deficiencies and loss of yield and quality. Where a supplemental source of Ca is required to rapidly meet plant demands, there are several excellent fluid and dry products that dissolve quickly and are widely available.

Standard soil tests in the West use ammonium acetate to simultaneously extract Ca, Mg, and K. There is evidence that traditional soil extracts may actually dissolve some of the Ca-containing minerals that are not typically available for plant uptake, thereby overestimating exchangeable Ca. Some labs suggest that results from a saturated soil paste extract may provide more accurate information regarding Ca availability.

**Ca in Plants** Similar to the requirement of Ca in human diets to strengthen bones, plants need Ca to strengthen cell walls and for protection from stress. Calcium is largely taken up by plants at the root tips and moves in the xylem through the plant, but not the phloem. When plants have insufficient Ca, cell walls and membranes will weaken and disintegrate, leading to increased disease, fruit rotting, and postharvest problems. When Ca is not delivered through the plant in the required quantity, fruit disorders such as blossom-end rot appear on tomatoes and peppers. Similarly, tip burn in lettuce develops when the older, outer leaves get adequate Ca with active transpiration, but the younger, internal leaves do not draw much Ca from the xylem and develop symptoms of browning.

**General mobility of elements in the phloem.**

| Immobile | Intermediate | Mobile |
|---|---|---|
| Calcium | Sodium | Potassium |
| Boron * | Iron | Nitrogen |
| | Manganese | Magnesium |
| | Zinc | Phosphorus |
| | Copper | Boron* |
| | Molybdenum | Sulfur |
| | | Chloride |

* Boron is generally immobile in most plants. Some fruit and nut trees are notable exceptions

### Magnesium

Magnesium is always present as $Mg^{2+}$ in the soil. The behavior of Mg in soil is rather similar to Ca in most regards. It is generally present at lower concentrations than Ca, except in some Western soils that have developed from Mg-rich parent material where an abnormally high ratio of Mg/Ca occasionally causes nutritional problems.

The most visible role of Mg in the plant is its presence in the center of chlorophyll molecules (**Figure 1**). Consequently, Mg deficiencies first appear as unusually light green leaves. Magnesium also activates more essential plant enzymes than does any other mineral nutrient.

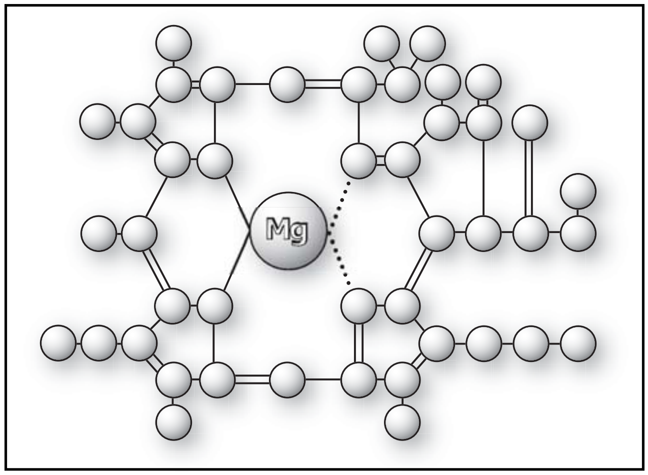



**Figure 1. Chlorophyll molecules are formed around a central atom of Mg.**

There are several excellent sources of Mg that can supply this nutrient where required. Dolomitic lime (a combination of $CaCO_3$ and $MgCO_3$) is commonly used in areas where there is a need for increasing the soil pH, but this material will not readily dissolve in neutral or alkaline soils. Other good sources of Mg include $K_2SO_4{\cdot}MgSO_4$ and $MgSO_4{\cdot}7H_2O$.

Soils containing excessively high Mg may suffer from clay dispersion and surface sealing, since Ca is more effective at improving these soil properties than is Mg, even though they are both divalent cations. This is likely due to the larger hydrated radius of Mg than Ca (**Table 1**).

**Table 1. Cation size and the hydrated cation size typically found in soil solution.**

| Cation | Non-hydrated radius | Hydrated radius |
|---|---|---|
| | - - - - - - - - - - - - nm | - - - - - - - - - - - - |
| $Na^{+}$ | 0.095 | 0.36 |
| $K^{+}$ | 0.133 | 0.33 |
| $Mg^{2+}$ | 0.066 | 0.43 |
| $Ca^{2+}$ | 0.099 | 0.41 |
| $Al^{3+}$ | 0.050 | 0.48 |

### Potassium

Potassium is not held as tightly on the soil exchange sites as Ca or Mg, and is consequently slightly more mobile in soil solution. Annual movement of K is generally less than ½ in. in most soils, but may move as much as a few inches in a sandy soil where considerable rainfall or irrigation water is present.

Potassium does not become part of any cell structure in plants, but is present in all cells as free $K^{+}$ in solution. When there is there is an abundant supply of K, excess K is stored in the cell vacuole where it can be withdrawn in times of need. The term “luxury consumption” might be better termed “contingency supply” to provide for growth periods when adequate K may not be available.

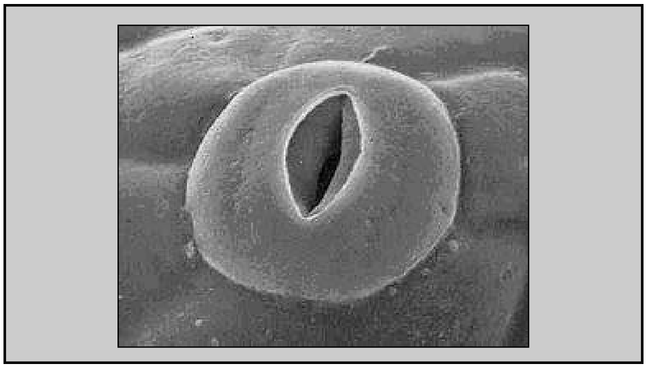


**Figure 2.** **Proper opening and closing of the guard cells in leaf stomata is largely governed by K.**

Although K has an essential role in plants for enzyme activation, its most important function is as a counter-ion in almost all plant reactions, including protein formation. The unique function of K in controlling the guard cells in the leaf stomata also deserves special mention (**Figure 2**)

### Is There an Ideal Ratio of these Cations?

There is no single ideal ratio of these cations in all soils. This theory of an "ideal cation proportion" was first introduced in the 1930s and 1940s. The proposed ratios were 65% Ca, 10% Mg, 5% K, and 20% H. The concept, frequently referred to as the "base cation saturation ratio" (BCSR), has been repeatedly examined for over 60 years in greenhouse, field, and laboratory research and is consistently reported to be unfounded. A plant grown with these specific cation ratios would not have any cation nutrition problems, but there is no evidence that they will grow better or have superior cation nutrition than plants fertilized according to traditional soil testing recommendations.

While an adequate cation supply is essential for plants, there is no one ratio that must be forced in all situations, as evidenced by the productive agriculture that occurs under very diverse global soil conditions…as long as certain minimum requirements are met. Trying to achieve a single "ideal" ratio under all circumstances is unnecessary for plant growth and frequently very expensive to reach and maintain. Consider the problem posed in calcareous soils where soil Ca levels are high, but Mg and K levels are more than sufficient as well. With the BCSR approach, additional Mg and K are generally recommended to counterbalance the abundant Ca, but no crop responses are observed.

The BCSR concept has been applied in hydroponic production, but even there the concentrations of the cations are also important, not just their ratio. Additionally, nutrient requirements change as the plant develops and different crops have different nutrient ratios in their vegetative and reproductive parts. Soils are commonly sampled in the 0 to 6 in. depth, while roots extend far below this depth. So where should the BCSR be measured? The notion of maintaining some $H^+$ on the exchange sites was popular in the 1940s, especially in the acid soils where this concept was developed. We now understand that measurement of exchangeable $H^+$ is largely a result of lab procedures and that it does not occur on most soil exchange sites, particularly in common Western soils. The BCSR system may be most useful for identifying extreme cation ratios that need special attention and correction.

Testing and validating the BCSR system has not been simple, but there has been a large amount of research done on the subject by prominent scientists. Although the BCSR approach is consistently shown to offer no advantages, it is a popular notion that has very little theoretical basis and even less research to support it. A selection of scientific literature on the subject is available at the website: >**www.ppi-ppic.org/west/bcsr**<.

This review of cations in the soil reinforces the importance of regular soil testing to make sure that none of the essential nutrients becomes limiting to growth and quality. Since these major cations are relatively simple to manage and do not usually cause any major environmental problems, it is easy to forget their importance for maintaining plant nutrition. Use modern soil recommendations to keep cations adequately supplied for growing plants and don't be tempted to use old and misguided philosophies that have almost no support in the scientific community. ■

**Review of Cation Exchange**

Due to imperfections in the chemical structure of clay crystals, almost all common clays contain a negative charge (referred to as the *permanent* negative charge due to isomorphic substitution). Soils also have a *pH-dependent* charge on their surface, which means that there are more cation exchange sites on clay and organic matter as the pH increases and fewer as the pH declines.

Positively charged cations are attracted to the negatively charged surfaces where they are held by electrostatic attraction. Due to its di-polar nature, water is attracted to the positively charged cations, creating a shell of water (or hydration) around each individual cation. It is both the hydrated cation **size** and **charge** that determine its ability to bind on cation exchange sites. The strength of the bond between clay and a cation is determined by the charge density, the relationship between the number of positive charges divided by its size.

Based on these principles, the relative ability of a cation to replace another (if present in equivalent quantities) is generalized by the Lyotropic Series.

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

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**Potash & Phosphate Institute (PPI)**
655 Engineering Drive, Suite 110
Norcross, GA 30092-2837

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