



Soil Nutrient Handbook

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Photos are provided courtesy of the International Plant Nutrition Institute (IPNI) and its IPNI Crop Nutrient Deficiency Image Collection. The photos are a sample of a greater collection, which provides a comprehensive sampling of hundreds of classic cases of crop deficiency from research plots and farm fields located around the world. For access to the full collection, you can visit IPNI's website.

Primary Nutrients

Nitrogen – (N)

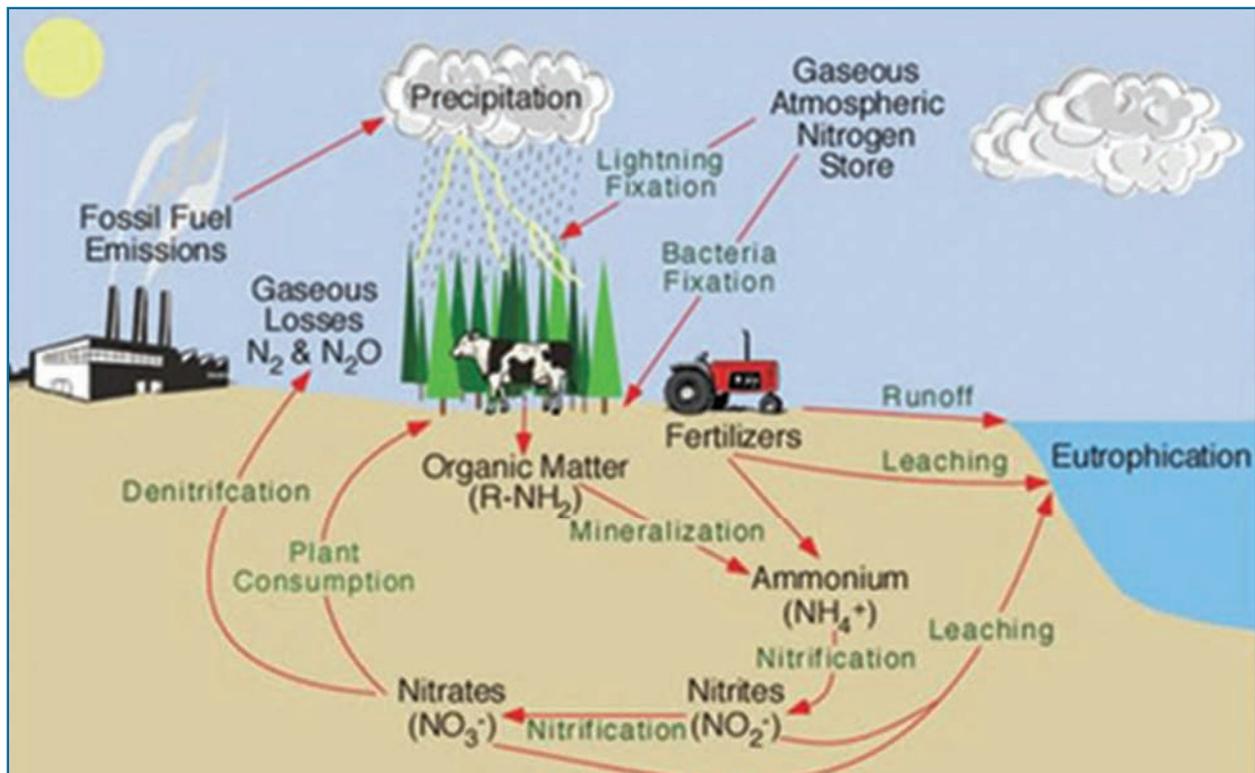
Nitrogen in Soils

- Nitrogen in soils can be supplied by:
 - Commercial Fertilizer, Atmospheric, Organic Matter, Crop Residues, Animal Manures
- Nitrogen Changes in Soil Profile
 - Nitrification
 - Nitrification is a biological process where bacteria transform NH_4 into NO_3 . Proceeds rapidly under warm, moist and well aerated soil conditions
 - Ammonium (NH_4) is stable in soil until nitrification occurs ($\text{NH}_4 \rightarrow \text{NO}_3$)
 - Denitrification
 - Bacteria convert nitrate (NO_3) to N gases and lost to the atmosphere under saturated soils (anaerobic conditions). Some anaerobic bacteria in water logged soils get oxygen from NO_3 to produce N_2 which is then released to the atmosphere.
 - Leaching
 - Nitrate carries a negative charge and is repelled by the negatively charged soil particles. This allows nitrate to leach with water infiltration.
 - Nitrate loss down the soil structure with water
 - Volatilization
 - Occurs when Ammonia (NH_3) isn't converted to Ammonium (NH_4) lost to the atmosphere as a gas.
 - Volatilization can occur during
 - Unincorporated nitrogen fertilizers into soil surface
 - High soil temperatures, warm and windy weather
 - Moist, drying soil conditions

Nitrogen Role in Plant Growth

- Essential in formation of Amino Acids – the building blocks of protein
- Part of DNA molecule – responsible for cell division and reproduction and plant growth
- Part of Chlorophyll molecule (the light receptor of plants – turns light energy into plant energy)
- Aids in production and usage of carbohydrates
- Affects energy reaction in plants and is a key component of vitamins

Nitrogen Cycle



Nitrogen Deficiency Symptoms in Plants

Nitrogen is mobile in plants, meaning it can move to areas where the nutrient is needed. In plants, nitrogen deficiencies first show up on the oldest plant tissues. Symptoms advance up the plant to younger leaves. In Corn, nitrogen deficient plants are spindly, pale and stunted. Lower leaves develop a yellow-orange color in the shape of an inverted “V” beginning at the tip and following the midvein. Leaves may begin to die (fire) at the tip. Ears are small and pinched at the tip. Symptoms are favored by cold, ponded, dry or low organic matter soil and incorporation of low-nitrogen residues.



Nitrogen Soil Testing Procedure

Most calibrations for Nitrate-Nitrogen are based on sampling depth, geographic location, and time of year. Fertilizer nitrogen is just one of the nitrogen sources that plants utilize. Another common source is released by the mineralization of organic matter, therefore, requires proper evaluation. The relative level of nitrate-nitrogen is variable and depends on the season, water saturated soils (lack of oxygen), leaching, and level of OM.

To accurately predict nitrate-nitrogen in the root zone, subsurface soil samples should be collected to a depth of at least 2 feet. Deeper sampling for nitrate-nitrogen can give a good indication of residual N for future crops in drier growing areas.

0-24" Nitrate Concentrations

- **Very Low** (<25 lbs./acre)
- **Low** (26-50 lbs./acre)
- **Medium** (51-75 lbs./acre)
- **High** (76-100 lbs./acre)
- **Very High** (100+ lbs./acre)

Pre-sidedress Nitrate Test (PSNT) is an in-season soil nitrate test that can be used to determine if additional fertilizer nitrogen (N) is needed for corn. This test should be conducted on soil samples taken from a one foot depth. Soil samples should be collected when corn plants are 6 to 12 inches tall (measured from the ground surface to the center of the whorl).

PSNT Concentrations

- **Low** (<10 ppm)
- **Deficient** (11-15 ppm)
- **Moderately Deficient** (16-25 ppm)
- **Adequate** (25+ ppm)

Primary Nutrients - Phosphorus – (P)

Phosphorus in Soils

Phosphorus exists in soil as both an organic form and inorganic forms. Organic forms are found in humus or other organic materials. Through the process of mineralization by microorganisms, organic phosphorus is released into a soluble form from the breakdown of organic matter for plant growth. Soil temperature and moisture have an effect how much mineralization takes place. In general, the most mineralization takes place when soils are warm and well drained.

Inorganic phosphorous occurs when phosphorus combines with iron (Fe), aluminum (Al) and calcium (Ca). The phosphorus reacts with these elements to produce a form of phosphorous that is not very soluble, fixed or “tied-up” by the soil. The solubility of the various inorganic phosphorous compounds have a direct impact on the availability of phosphorous for crop growth. Phosphorous solubility is related to soil pH. In very low pH’s (less than 5.0), iron and aluminum fix phosphorous availability. With a pH of 7.3 or above, fixation of phosphorous by calcium is a concern. Phosphorous that is fixed is not measured by routine soil test procedures.

Phosphorus Role in Plant Growth

- Part of ATP Molecule which circulates energy through the plant
- Part of organic compounds found in plants
- Stores and transfers energy to drive reactions within cells that promote photosynthesis and respiration
- Enhances cell division/enlargement
- Promotes root formation, early plant growth, and hastens maturity
- Improves hardiness, seed quality, and disease resistance

Phosphorous Deficiency Symptoms



In corn, leaves of young phosphorus-deficient plants are bluish-green and slightly narrowed, turning reddish-purple starting at the tips and along the edges. Leaf tips may die. If conditions for phosphorous uptake improve, newer leaves may be symptom-free. Symptoms are seldom observed on knee-high and larger plants. Ears may be small and misshaped, twisted with one or more kernel rows missing on one side.

In soybeans, phosphorous deficiencies generally appear as thin and dwarfed stems, lack-luster or blue-green upward pointing leaves, and general early defoliation. Leaves tend to be more erect and form an acute angle with the stem. A limited supply of phosphorus reduces the number, as well as the efficiency, of nodulating bacteria. Phosphorus deficiency is easily diagnosed through soil testing, but difficult to correct within the crop year.

Phosphorous Soil Test Procedures

MVTL uses three extraction methods to determine available phosphorous based upon our customers' needs.

Olsen-Bicarbonate is generally used where soil pH is at or above 7.2. This method has a known reliability in alkaline soils with medium to high CEC levels, as well as, free lime or calcareous soils. *Bray I* is best adapted to fine-textured soils where the pH levels are well below 7.0. *Bray I* methods typically do not perform well in high lime soils and/or higher CEC's. The *Mehlich III* method is used in much of Iowa. It has proven to be a more stable method versus Bray, because it can adjust to excess (free) lime and a larger pH scale. In all three testing methods, P is extracted from the soil; a developing agent is added to the extract to change the color and the intensity is read by the colorimeter.

Concentrations

Bray & Mehlich III –

- **Very Low** (0-8 ppm)
- **Low** (9-15 ppm)
- **Optimum** (16-20 ppm)
- **High** (21-30 ppm)
- **Very High** (31+ ppm)

Olsen –

- **Very Low** (0-5 ppm)
- **Low** (6-9 ppm)
- **Optimum** (10-13 ppm)
- **High** (14-18 ppm)
- **Very High** (19+ ppm)

Iowa State University (ISU) recognizes Mehlich III method using the inductively coupled plasma (ICP) instrument to measure P extracted from the soil. The ICP instrument measures all P forms in the soil sample and results in higher P test values. This testing method should not be confused with the regular Mehlich III test using colormetric method. ISU provides recommendations for this testing method.

Bray & Mehlich III (ICP) Method –

- **Very Low** (0-15 ppm)
- **Low** (16-25 ppm)
- **Optimum** (26-35 ppm)
- **High** (36-45 ppm)
- **Very High** (46+ ppm)

Recommendations are given according to crop removals and build levels of lower testing soils. Economics, farming practices, land tenure by individual producers should be examined when making further recommendations. Soils testing very low to low will have the greatest benefit and return from nutrient applications. Soils testing very high in most cases will not benefit from additional phosphorus fertilizer.

Primary Nutrients

Potassium – (K)

Potassium in Soils

In general, huge quantities of potassium are found in soil. The majority of it is found in the structural component of the soil minerals and is not available for plant growth. Due to differences in parent materials and the effect of weathering rates on soil, the amount of potassium the soil generates for plant growth varies and often the need to supply potassium as a fertilizer is warranted for crop production. Three forms of potassium exist in soils: Unavailable K, Slowly Available K, and Readily Available K.

- **Unavailable K**

90-98% of K found in soil is unavailable for plant uptake. Most of this is found in feldspars and micas, which are crystalline forms of K which plants aren't able to use. Over a long period of time, the weathering process breaks down the crystals and the K is released to a slowly available form. This process is slow and cannot supply the full needs of field crops

- **Slowly Available K**

This form of K is thought to be trapped or fixed between layers of clay minerals and not as readily available for plant uptake. While some slowly available K is released during the growing season, some readily available K is fixed between layers of clay to be converted to slowly available K. The amount of K that can be fixed varies with the types of clay across the landscape. In areas where Montmorillonite clays dominate (central, western Minnesota), these soils fix K when soils become dry by trapping it between layers of clay minerals. They also release K when soil becomes wet.

- **Readily Available K**

Potassium that is water soluble, or dissolved in soil water and held on the exchange sites of clay particles (exchangeable K) is considered readily available for plant growth. This is the form of K that routine soil test measure.

Potassium Role in Plant Growth

- Associated with the movement of water, nutrients and carbohydrates in plant tissue
- Stimulates early growth
- Enhancing protein production
- Improves seed quality, plant hardiness, and disease resistance

Potassium Deficiency Symptoms



In plants, K is mobile and will move from the lower leaves to the upper leaves. For Corn, symptoms first show up in the lower leaves with the leaf margins turning brown and the remainder of the leaf has a lighter green, striped appearance. The striping appearance can also be confused with sulfur, magnesium and zinc deficiencies. In soybeans, the margins of the leaf turn a lighter shade of green or yellow, again on the lower leaves.

Potassium Soil Testing Procedures

Potassium is extracted from the soil using an ammonium acetate solution or Mehlich III extract. The concentration is then obtained by analyzing the extracting solution using an Inductively Coupled Plasma (ICP) Spectrometry. This amount is considered readily available or exchangeable potassium. The amount or percent of exchangeable potassium needs to be higher on sandy soils (lower CEC's), but on clay soils (higher CEC's) it can be lower and still supply the plants with enough potassium.

Concentrations Ammonium Acetate and Mehlich III

- **Very Low** (0-120 ppm)
- **Low** (121-160 ppm)
- **Optimum** (161-200 ppm)
- **High** (201-240 ppm)
- **Very High** (241+ ppm)

Soil recommendations are given according to crop removals and building soil test levels, but economics and farming practices by individual producers should be examined when making further recommendations. Soils testing below 160 ppm will benefit the most from potassium fertilizers. For soils testing over 240 ppm, adding potassium fertilizer may not increase crop yields.

Secondary Nutrients

Sulfur – (S)

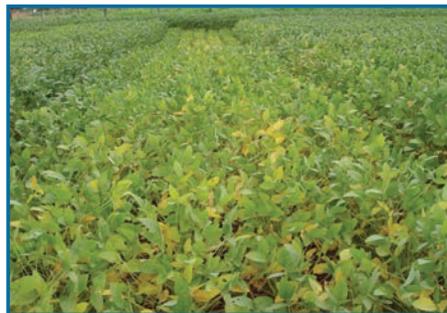
Sulfur in Soils

The majority of sulfur in soil is supplied by organic matter, while smaller amounts of sulfur are supplied by soil minerals, atmosphere and fertilizers. Sulfur is generally removed from the soil by two ways, either through crop removal and/or is mobile and affected by leaching down the soil profile, much like nitrate. Sulfur is a mobile nutrient and can be difficult to fully assess with just a 6-8 inch deep soil sample.

Sulfur Role in Plant Growth

- Integral part in the formation of amino acids
- Helps to develop enzymes and vitamins
- Promoter of nodule formations on legumes
- Aids seed production
- Necessary for chlorophyll formation

Sulfur Plant Deficiency Symptoms



When S is deficient, growth is reduced and maturity is delayed. Also, inadequate supplies of S can cause a reduction in protein formation. In corn, deficiencies of S causes stunted, slow-growing and yellow plants. Yellowing occurs between veins, especially of younger (upper) leaves. Older plants rarely show symptoms. Symptoms are favored by cold, wet soil, low pH and low organic matter. In soybeans, stunted plants, pale green color, similar to nitrogen deficiency except chlorosis may be more apparent on upper leaves. In alfalfa and clover, the entire leaf area has a light green color.

Sulfur Soil Testing Procedures

Extractable sulfur is reported in ppm of sulfate-sulfur. The determination is made on a 0-6" or 0-24" sample.

Concentrations

- **Very Low** (0-3 ppm)
- **Low** (4-7 ppm)
- **Medium** (7-11 ppm)
- **High** (11-15 ppm)
- **Very High** (15+ ppm)

Optimum levels of S depend largely on organic matter content, soil texture, drainage and yield goals. Sulfur can be limited with soils low in organic matter, since organic matter is the primary source of sulfur in soils. Soil tests for available sulfur are helpful, but in general are not as precise as phosphorous or potassium. Sulfur is in a constant state of change in the soil similar to nitrogen.

Recent research indicates crop responses are occurring even in soils with good soil organic matter. This can be attributed to less atmospheric sulfur. Use 25 lb. S per acre for broadcast applications on sandy soils. Medium and fine texture soils with organic matter levels <4.0% apply 10-15 lb. S broadcast per acre. Soils with organic matter >4.0% where corn follows corn and high surface residue, sulfur applications of 10-15 lb. S broadcast or 6-10 lb. per acre banded may be beneficial.

Secondary Nutrients

Calcium – (Ca)

Calcium in Soils

Calcium is present in adequate amounts in most soils. Calcium is a component of several primary and secondary minerals in the soil, which are essentially insoluble for agricultural considerations. These materials are the original sources of the soluble or available forms of Ca. Calcium is also present in relatively soluble forms, as a cation (positively charged Ca^{++}) adsorbed to the soil colloidal complex. The ionic form is considered available to crops.

Calcium is found in many of the primary or secondary minerals in the soil. In this state it is relatively insoluble. Calcium is not considered a leachable nutrient. However, over hundreds of years, it will move deeper into the soil. Because of this, and the fact that many soils are derived from limestone bedrock, many soils have higher levels of Ca, and a higher pH in the subsoil.

- **Soil pH:** Acid soils have less Ca, and high pH soils normally have more. As the soil pH increases above pH 7.2, due to additional soil Ca, the additional “free” Ca is not adsorbed onto the soil. Much of the free Ca forms nearly insoluble compounds with other elements such as phosphorus (P), thus making P less available.
- **Soil Cation Exchange Capacity (CEC):** Lower CEC soils hold less Ca, and high CEC soils hold more.
- **Cation competition:** Abnormally high levels, or application rates of other cations, in the presence of low to moderate soil Ca levels tends to reduce the uptake of Ca.
- **Alkaline sodic soil (high sodium content):** Excess sodium (Na) in the soil competes with Ca, and other cations to reduce their availability to crops.
- **Sub-soil or parent material:** Soils derived from limestone, marl, or other high Ca minerals will tend to have high Ca levels, while those derived from shale or sandstone will tend to have lower levels.

Calcium Role in Plant Growth

- Strengthen cell walls and structure
- Helps prevent disease
- Increases plant metabolism – promotes early root growth and formation
- Improves soil acidity

Interactions

- **Other cations:** Being a major cation, calcium availability is related to the soil CEC, and it is in competition with other major cations such as sodium (Na^+), potassium (K^+), magnesium (Mg^{++}), Ammonium (NH_4^+), iron (Fe^{++}), and aluminum (Al^{+++}) for uptake by the crop. High K applications have been known to reduce the Ca uptake in apples, which are extremely susceptible to poor Ca uptake and translocation within the tree.
- **Sodium(Na^+):** High levels of soil Na will displace Ca and lead to Ca leaching. This can result in poor soil structure and possible Na toxicity to the crop. Conversely, applications of soluble Ca, typically as gypsum, are commonly used to desalinate sodic soils through the displacement principle in reverse.
- **Phosphorus(P):** As the soil pH is increased above pH 7.0, free or un-combined Ca begins to accumulate in the soil. This Ca is available to interact with other nutrients. Soluble P is an anion, meaning it has a negative charge. Any free Ca reacts with P to form insoluble (or very slowly soluble) Ca-P compounds that are not readily available to plants. Since there is typically much more available Ca in the soil than P, this interaction nearly always results in less P availability.
- **Iron(Fe^{++}) and Aluminum(Al^{+++}):** As the pH of a soil decreases, more of these elements become soluble and combine with Ca to essentially insoluble compounds.
- **Boron(B-):** High soil or plant Calcium levels can inhibit B uptake and utilization. Calcium sprays and soil applications have been effectively used to help detoxify B over-applications.

Calcium Deficiency Symptoms

Calcium deficiency symptoms can be rather vague since the situation often is accompanied by a low soil pH. Visible deficiency symptoms are seldom seen in agronomic crops but will typically include a failure of the new growth to develop properly. Annual grasses such as corn will have deformed emerging leaves that fail to unroll from the whorl. The new leaves are often chlorotic. Extremely acid soils can introduce an entirely new set of symptoms, often from different toxicity's and deficiencies.

Calcium Soil Testing Procedures

Calcium is extracted from the soils using ammonium acetate solution or Mehlich III extract and reported in ppm. Knowing the amount of exchangeable Ca is an important for the calculation of the *Cation Exchange Capacity* (CEC) by summation. Ca deficiencies are most likely in coarse textured soils with pH less than 6.0.

Concentrations

- **Very Low** (0-250 ppm)
- **Low** (251-500 ppm)
- **Medium** (501-2500 ppm)
- **High** (2501-5000 ppm)
- **Very High** (5000+ ppm)

Secondary Nutrients

Magnesium – (Mg)

Magnesium in Soils

Magnesium is a component of several primary and secondary minerals in the soil, which are essentially insoluble, for agricultural considerations. These materials are the original sources of the soluble or available forms of Mg. Magnesium is also present in relatively soluble forms, and is found in ionic form (Mg^{++}) adhered to the soil colloidal complex. The ionic form is considered to be available to crops.

Magnesium Role in Plant Growth

- Key element in chlorophyll production
- Improves efficiency and mobility of phosphorus and iron
- Activates enzymes

Factors Affecting Availability

- **Soil Mg content:** Soils inherently low or high in Mg containing minerals.
- **Soil pH:** Low soil pH decreases Mg availability, and high soil pH increases availability
- **Soil Mg:Mn ratio:** High available Mn can directly reduce Mg uptake. This may be independent of the acid conditions normally associated with excess available Mn in the soil.
- **Soil CEC:** Low CEC soils hold less Mg, while high CEC soils can hold abundant Mg. However, if a high CEC soil does not happen to have strong levels of Mg, it will tend to release less of the Mg that it holds to the crop.
- **Cation competition:** Soil with high levels of K or Ca will typically provide less Mg to the crop
- **High cation applications:** High application rates of other cations, especially K, can reduce the uptake of Mg. This is most common on grasses, and corn seems to be the most sensitive grass.
- **Low soil temperatures**

Interactions

- **Other cations:** Being a major cation, Mg availability is related to the soil CEC, and it is in competition with other major cations such as calcium (Ca^{++}), potassium (K^+), sodium (Na^+), ammonium (NH_4^+), iron (Fe^{++}), and aluminum (Al^{+++}).
- **Phosphorus:** Phosphorus uptake is often enhanced when applied with Mg fertilizers. However, mixing some liquid or suspension sources of P and Mg can lead to a reaction can result in the formation of a large amount of precipitated material, to the point of near solidification of the mixture.
- **Sulfur:** Sulfur leaching is often increased where supplemental Magnesium is applied

Magnesium Deficiency Symptoms



The classic deficiency symptom is interveinal chlorosis of the lower/older leaves. However, the first symptom is generally a more pale green color that may be more pronounced in the lower/older leaves. In some plants, the leaf margins will curve upward or turn a red-brown to purple in color. Full season symptoms include preharvest leaf drop, weakened stalks, and long branched roots.

Magnesium Soil Testing Procedures

Magnesium is extracted from the soils using ammonium acetate solution or Mehlich III extract and reported in ppm. Knowing the amount of exchangeable Mg is important for the calculation of the *Cation Exchange Capacity* (CEC) by summation. Mg deficiencies are most likely in coarse textured soils with pH less than 6.0.

Toxicity

Magnesium toxicity's are rare. Crops grown on heavy montmorillonite clay soils that have been poorly fertilized with potassium may exhibit excesses of magnesium in their tissue. But, before the tissue level approaches toxicity, potassium deficiency will occur. Higher tissue levels of magnesium are usually found in the older leaves on the plant and may be associated with diseased or damaged leaves.

Concentrations

- **Low** (0-50 ppm)
- **Medium** (51-150 ppm)
- **High** (150+ ppm)

Soil testing is the first step in determining a need. If the analysis shows a need and a supplemental application is indicated, you can be confident the application will be economically sound. As always plant tissue analyses are also useful in uncovering “hidden”; Magnesium shortages and when a need is determined, treatment should follow. Magnesium is a constituent of most agricultural lime, as well as specific Mg fertilizers. Magnesium containing materials applied to the soil may serve two functions. Correcting problems is often difficult. Proper liming with dolomitic limestone is almost always the most practical solution to low Mg, even if the dolomite is more expensive. Supplemental broadcast and row applications will most likely need to be repeated over a period of several years. If row applied fertilizers are used where magnesium shortage is a problem, it is desirable to minimize in-row K applications to avoid K-Mg competition. However, materials such as Sul-Po-Mag and K-Mag that contain both nutrients have been used to partially satisfy Mg needs on soils where the crops had significant Mg stress caused by extremely high K levels.

Micro-Nutrients

Zinc – (Zn)

Zinc Role in Plant Growth

- Vital to enzyme system
- Allows plant to efficiently metabolize other crop nutrients
- Necessary for chlorophyll production, carbohydrate and starch formation
- Aids in seed formation

Zinc Deficiency Symptoms



Plants fail to develop normally in soils that are deficient of Zn. In corn, symptoms of Zn deficiency are rare beyond the seedling stage. Yellow to white bleached bands appear on the lower part of leaves while the midvein, margins and tip remain green. The deficiency is favored by high soil phosphorus, high pH, cool, wet soil and low organic matter. Also, lack of normal elongation between internodes of corn is a common symptom.

Need for Zinc Fertilizers

Under these conditions, a response to Zn fertilizer might be expected

- **Soil Temperature.** Cool soil temperatures in early spring can intensify the need for Zn. When soils are cold, the organic matter does not decompose and Zn is not released and available for crop growth.
- **Soil Texture.** Most of the response to Zn in a fertilizer program will take place on fine-textured soils. Recent research on sandy soils indicates a response to Zn can occur when high yields are grown on sandy soils with a low organic matter content. The measured response to Zn fertilization in these situations has been small and has not occurred every year. *Use the zinc soil test to determine if Zn is needed in a fertilizer program.*
- **Topsoil Removal.** The probability of a response to Zn fertilization increases where topsoil has been removed or eroded away. When soils are eroded, the amount of free calcium carbonate on the soil surface increases. The probability of the need for Zn in a fertilizer program increases as the percentage of free calcium carbonate increases.

- **Previous Crop.** The probability of a response to Zn fertilization increases if either corn or dry edible beans follows a crop of sugar beets.
- **Phosphorus Levels.** There is a known relationship between phosphorus (P) and (Zn) in soils. Excessive applications of phosphate fertilizers have caused a Zn deficiency in corn and reduced yields. The P-induced Zn deficiency might be a concern when high rates of manure are applied to crop land. The manure, however, also contains Zn that can be used for crop growth. Therefore, P supplied from manure should *not* create a Zn deficiency for crop production in Minnesota.

Zinc Soil Test Procedures

Zinc is extracted using a DTPA solution and reported in ppm. Soil test levels greater than 1.0 ppm are considered adequate for all crops.

Concentrations

- **Very Low** (0-.25 ppm)
- **Low** (.26-.50 ppm)
- **Medium** (.51-.75 ppm)
- **High** (.76-1.0 ppm)
- **Very High** (1.01+ ppm)

Micro Nutrients

Iron – (Fe)

Iron Role in Plant Growth

- Promotes formation of chlorophyll
- Used in reactions involving cell division and growth
- Acts as the plants oxygen carrier.

Factor affecting availability

- **Soil pH:** High soil pH reduces Fe availability while acid soils increase Fe availability. The high pH effect is increased in waterlogged, compacted, or other poorly aerated soils. One factor in this effect is the presence of high carbonates in the soil, which also plays a role in waterlogged soils and in the root rhizosphere reaction to certain other nutrients and fertilizer sources.
- **Low Organic Matter:** In addition to being a source of Fe, O.M. compounds are able to form Fe complexes that improve availability.
- **Saturated, Compacted, or Other Poorly Aerated Soils:** In acid soils, this condition can increase Fe availability (to the point of toxicity).
- **High Soil P:** Excessive amounts of soluble P, or high rates of P fertilizer, have been demonstrated to inhibit Fe uptake in many crops.
- **HCO₃⁻ :** Iron deficiency can be induced by the presence of the bicarbonate ion in the soil (saline and alkali conditions).

Iron Deficiency Symptoms



Interveinal chlorosis of young leaves. Severe deficiencies may progressively affect the entire plant turning the leaves from yellow to bleached-white. Luckily, most agricultural soils provide an abundant supply of Fe to plants. Because iron can be more difficult to use in a fertility program than other nutrients, most soil application methods are often not very effective, while multiple foliar applications are often too expensive, or labor intensive.

Iron Soil Testing Procedures

These levels are determined using DTPA extraction and reported in ppm. Soils with test levels greater than 4.0 ppm (Fe) are unlikely to show a response to nutrient applications.

Concentrations

- **Very Low** (0-1.0 ppm)
- **Low** (1.1-2.0 ppm)
- **Medium** (2.1-4.5 ppm)
- **High** (4.6-10.0 ppm)
- **Very High** (10+ ppm)

Micro Nutrients

Manganese – (Mn)

Manganese Role in Plant Growth

- Aids enzymes and chlorophyll productions
- Increases the availability of phosphorous

Factors affecting availability

- **Soil pH:** High soil pH reduces Mn availability while low soil pH will increase availability, even to the point of toxicity.
- **Organic Matter:** Mn can be “tied up” by the organic matter such that high organic matter soils can be Mn deficient.
- **Soil Moisture:** Under short-term waterlogged conditions, plant available Mn^{++} can be reduced to Mn^{+} , which is unavailable to plants.

Manganese Deficiency Symptoms



Because Mn is not translocated in the plant, deficiency symptoms appear first on younger leaves. The most common symptoms on most plants are interveinal chlorosis. Sometimes a series of brownish-black specks appear in the affected areas. In small grains, grayish areas appear near the base of younger leaves. Manganese deficiencies occur most often on soils with a high pH and/or naturally low Mn content.

Toxicity

Manganese toxicity is a relatively common problem compared to other micronutrient toxicity. It normally is associated with soils of pH 5.5 or lower, but can occur whenever the soil pH is below 6.0. Symptoms include chlorosis and necrotic lesions on old leaves and dark-brown or red necrotic spots.

Manganese Soil Testing Procedures

These levels are determined using DTPA extraction and reported in ppm. Soils with test levels greater than 1.0 ppm (Mn) are unlikely to show a response to nutrient applications.

Concentrations

- **Very Low** (0-0.5 ppm)
- **Low** (0.6-1.0 ppm)
- **Medium** (1.1-2.0 ppm)
- **High** (2.1-4.0 ppm)
- **Very High** (4.1+ ppm)

Micro Nutrients

Copper – (Cu)

Copper Role in Plant Growth

- Involved in Chlorophyll formation and photosynthesis
- Needed for energy transfer in plants
- Promotes seed production and formation

Copper in Soils

The amount of Cu available to plants varies widely by soils. Available Cu can vary from 1 to 200 ppm in both mineral and organic soils as a function of soil pH and soil texture. The finer-textured mineral soils generally contain the highest amounts of Cu. The lowest concentrations are associated with the organic or peat soils. Availability of Cu is related to soil pH. As soil pH increases, the availability of this nutrient decreases. Copper is not mobile in soils and is attracted to soil organic matter and clay minerals.

Copper Deficiency Symptoms



Symptoms of Cu deficiency appear when small grains are grown on organic soils. Symptoms of Cu deficiency are almost never seen in corn/soybean production fields. These deficiency symptoms are characterized by a general light green to yellow color in the small grain crop. The leaf tips die back and the tips are twisted. A typical deficiency symptom for wheat is shown in the photographs. Cu deficiency is severe enough, growth of small grains ceases and plants die after reaching the tillering growth stage. Wheat will not have grain in the head. Deficiency symptoms have only been observed when small grains are grown on peat soils. Foliar applications of Cu can be an effective way to correct Cu deficiencies in small grains. Soil applications of Cu last for many years. Copper becomes attached to the soil organic matter and is not moved through the soil by water. Leaching is prevented, but the Cu is still available to plants. If the soil test for Cu is in the high range, annual applications of Cu are not needed.

Since large amounts of Cu in soils can be toxic to plants, it is important to accurately control applications. To avoid toxicity problems, annual applications of Cu should certainly be less than 40 lb. per acre. Toxicity problems are difficult to correct.

Copper Soil Test Procedures

These levels are determined using DTPA extraction and reported in ppm. Soils with test levels greater than 0.2 ppm are unlikely to show a response to nutrient applications.

Concentrations

- **Very Low** (0-0.10 ppm)
- **Low** (0.11-0.20 ppm)
- **Medium** (0.21-0.30 ppm)
- **High** (0.31-0.60 ppm)
- **Very High** (0.61+ ppm)

Micro Nutrients

Boron – (B)

Boron Role in Plant Growth

- Essential for seed and cell wall formation
- Necessary for sugar translocation
- Enhances plant maturity

Boron in Soils

Most soils are capable of supplying adequate amounts of boron for crop production. Research has shown, however, that using boron fertilizers will improve the yield of alfalfa and vegetables on some sandy soils. Where needed, use of boron can be profitable. A response to boron use might be expected on soils that have a sandy loam, loamy sand, or sand texture with low organic matter content. Most of the boron in soils is contained in the organic matter. As decomposition of organic matter takes place, boron is released for plant growth. Breakdown of organic matter is nearly stopped during dry weather.

Boron Deficiency Symptoms



Boron is not mobile in plants so deficiency symptoms will occur as stunting on the upper part of plants. With alfalfa, stunting of the new growth gives the plant a bushy, umbrella-like appearance. The lower (older) leaves stay green. Severely affected plants do not produce blossoms; an extensive yield loss occurs; and plants winterkill easily. When the deficiency is severe in alfalfa, the growing point dies.

Boron Soil Test Procedures

A boron level is determined by using DTPA-sorbitol to release boron from the soil and is reported in ppm. Many factors affect boron availability to plants. These include organic matter, soil texture, and soil pH. Crops like alfalfa, and many vegetable crops, tend to show the most response to added boron on deficient soils. Soils testing less than 1 ppm will likely be deficient, but following up with a plant analysis is recommended. Levels in excess of 4-5.0 ppm may be toxic to some crops.

Concentrations

- **Very Low** (0-0.10 ppm)
- **Low** (0.11-0.25 ppm)
- **Medium** (0.26-0.50 ppm)
- **High** (0.51-1.4 ppm)
- **Very High** (1.5+ ppm)

Chloride - Cl

Chloride role in plant growth

- It is essential (working in tandem with K^+) to the proper function of the plants stomatal openings, thus controlling internal water balance.
- It also functions in photosynthesis, specifically the water splitting system.
- It functions in cation balance and transport within the plant.
- Research has demonstrated that Cl diminishes the effects of fungal infections in an, as yet undefined, way.
- It is speculated that Cl competes with nitrate uptake tending to promote the use of ammonium N. This may be a factor in its role in disease suppression, since high plant nitrates have been associated with disease severity

Factors affecting availability

Most soil Cl is highly soluble and is found predominantly dissolved in the soil water. Chloride is found in the soil as the chloride anion. Being an anion it is fully mobile except where held by soil anion exchange sites (Kaolinite clays, Iron and Aluminum Oxides). In areas where rainfall is relatively high and internal soil drainage is good, it may be leached from the soil profile. Also, where muriate of potash fertilizer is not regularly applied chloride deficiencies can occur. Atmospheric chloride deposition tends to be rather high along coastal regions and decreases as you progress inland. Chloride, nitrate, sulfate, and boron are all anions in their available forms, and in that form they are antagonistic to each other. Therefore, an excess of one can decrease the availability of another.

Chloride Deficiency Symptoms



Wilting, restricted, and highly branched root system, often with stubby tips. Leaf mottling and leaflet blade tip wilting with chlorosis has also been observed. Chloride is reported in lbs./acre. Chloride is mobile in the soil and should be sampled at 0-24 inches.

Concentrations

- **Very Low** (0-15 lbs./acre)
- **Low** (16-30 lbs./acre)
- **Medium** (31-45 lbs./acre)
- **High** (46-60 lbs./acre)
- **Very High** (60+ lbs./acre)

Molybdenum – (Mo)

Molybdenum Role in Plant Growth

- Functions in converting nitrates (NO_3) into amino acids within the plant.
- Essential to the symbiotic nitrogen fixing bacteria in legumes.
- Essential to the conversion of inorganic P into organic forms in the plant.

Molybdenum Deficiency Symptoms

Molybdenum deficiency is rare. Young leaves sometimes twist, wilt and die along margins. Older leaves die at tips, along margins and between veins. Deficiency is favored by low pH and strong soil weathering. Excessive Molybdenum is toxic, especially to grazing animals.

Micro-Nutrient Sensitivity of Major Crops

Nutrient	Sensitive Crops	Soil Conditions Likely
Zinc	Corn	Soil Test < 1.5 ppm
	Edible Beans	High pH, Low O.M.
	Potatoes	Cool and wet soils
Boron	Alfalfa	Soil Test < 1.0 ppm
	Sugar Beets	High pH, Low O.M.
Copper	Wheat	Soil Test < 0.3 ppm
	Barley	High O.M.
Iron	Beans	Soil Test < 4.0 ppm
	Millet	High pH
	Sorghum	High carbonates
Manganese	Navy Beans	Soil Test < 2.0 ppm
	Soybeans & Oats	High pH
Molybdenum	Alfalfa	Soil Test < 0.1 ppm
	Peas	High pH
Chloride	Wheat	Soil Test < 7.0 ppm per depth
	Oats	Dryland soils testing
	Barley	High in potassium (K)

General considerations

Mobile Nutrients: These nutrients can be transferred from older tissues to youngest tissues within the plant. Symptoms are noticeable first on lower, oldest leaves.

- Nitrogen
- Phosphorus
- Potassium
- Magnesium

Immobile Nutrients: These nutrients are not easily transferred within the plant. Therefore, symptoms occur first on upper, youngest leaves.

- Boron
- Calcium
- Copper
- Iron
- Manganese
- Molybdenum
- Sulfur
- Zinc

Soil pH and Buffer pH

Soil pH

This is a measure of the soil acidity or alkalinity and is sometimes called the soil “water” pH. This is because it measures the pH of the soil solution, which is considered the active pH that affects plant growth. Soil pH is the foundation of essentially all soil chemistry and nutrient reaction and should be the first consideration when evaluating a soil test. The total range of the soil pH scale is from 0-14. Values below the mid-point (pH 7.0) are acidic and those above pH 7.0 are alkaline. A soil pH of 7.0 is considered to be neutral. Most plants perform best in a soil that is slightly acid to neutral (pH 6.2-7.). Some plants like blueberries require the soil to be more acid (pH 4.5-5.5), and others, like alfalfa will tolerate a slightly alkaline soil (pH 7.0-7.5).

Soil pH Measures Hydrogen Ion Activity

Soil pH	Acidity/Basicity Compared to pH 7.0
9.0	100
8.0	10
7.0	Neutral
6.0	10
5.0	100
4.0	1000

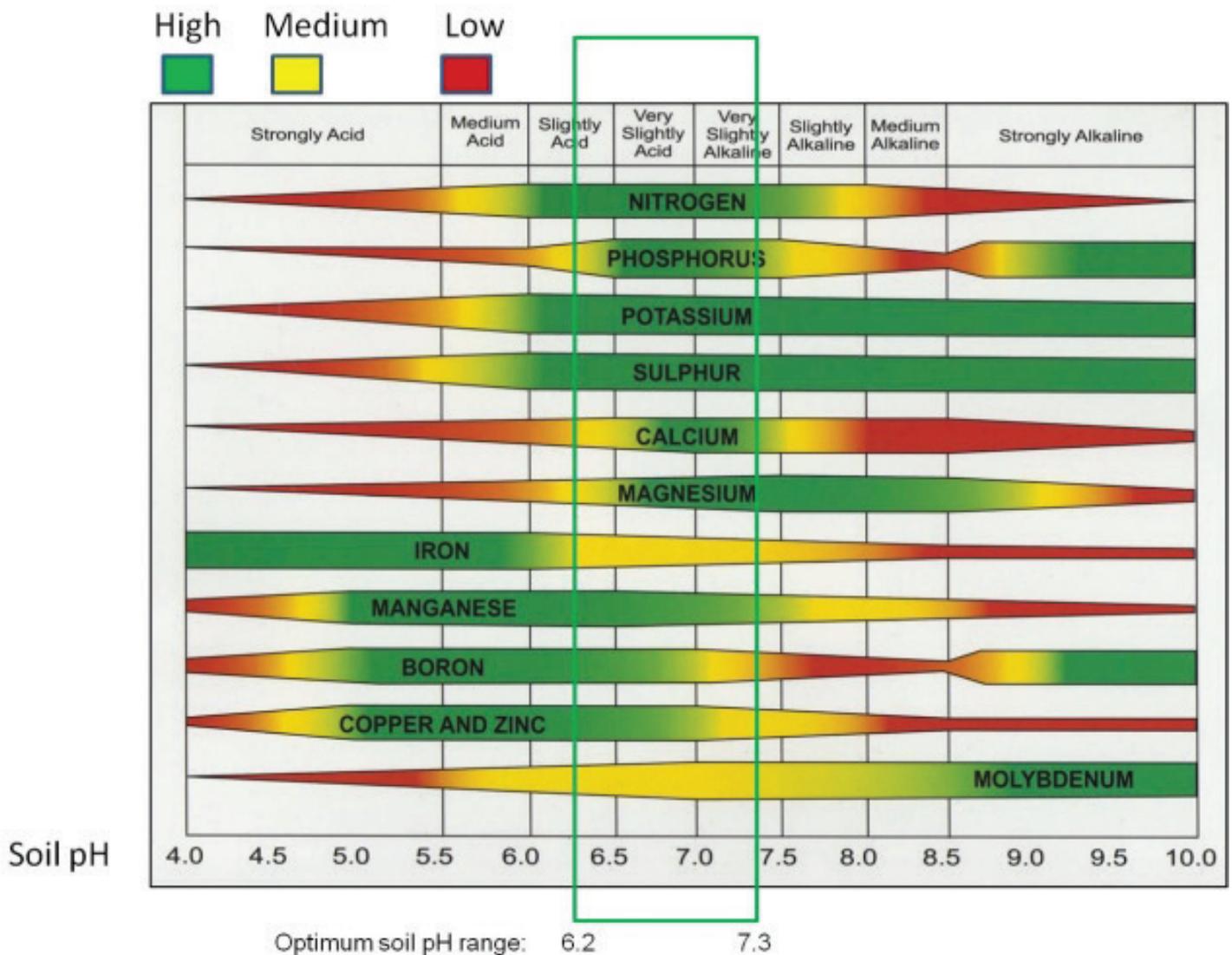
The soil pH scale is logarithmic; meaning that each whole number is a factor of 10 larger or smaller than the ones next to it. For example if a soil has a pH of 7.0 and this pH is lowered to pH 6.0, the acid content of that soil is increased 10-fold. If the pH is lowered further to pH 5.0, the acid content becomes 100 times greater than at pH 7.0. The logarithmic nature of the pH scale means that small changes in a soil pH can have large effects on nutrient availability and plant growth.

Buffer pH

This is a value that is generated in the laboratory; it is not an existing feature of the soil. Laboratories perform this test in order to develop lime recommendations.

In basic terms, the BpH is the resulting sample pH after the laboratory has added a liming material. In this test, the laboratory adds a chemical mixture called a buffering solution. This solution functions like extremely fast-acting lime. Each soil sample receives the same amount of buffering solution; therefore the resulting pH is different for each sample. To determine a lime recommendation, the laboratory looks at the difference between the original soil pH and the ending pH after the buffering solution has reacted with the soil. If the difference between the two pH measurements is large, it means that the soil pH is easily changed, and a low rate of lime will be sufficient. If the soil pH changes only a little after the buffering solution has reacted, it means that the soil pH is difficult to change and a larger lime addition is needed to reach the desired pH for the crop.

How soil pH affects availability of plant nutrients



Organic Matter

Percent OM is determined by the dry combustion method. OM content in soil is, especially, important for determining nitrogen and sulfur needs. The OM% along with soil texture can be very important when determining rates of certain soil-applied herbicides.

- **Very Low** (0-1.5%)
- **Low** (1.6-3%)
- **Medium** (3.1-4.5%)
- **High** (4.6-6.0%)
- **Very High** (6.0% +)

Organic Matter Role in Soils

- **Nutrient Supply**-Organic matter is a reservoir of nutrients that can be released to the soil.
- **Water-Holding Capacity**-Organic matter behaves somewhat like a sponge, with the ability to absorb and hold up to 90 percent of its weight in water. A great advantage of the water-holding capacity of organic matter is that the matter will release most of the water that it absorbs to plants. In contrast, clay holds great quantities of water, but much of it is unavailable to plants.
- **Soil Structure Aggregation**-Organic matter causes soil to clump and form soil aggregates, which improves soil structure. With better soil structure, permeability (infiltration of water through the soil) improves, in turn improving the soil's ability to take up and hold water.
- **Erosion Prevention**-The property of organic matter is not widely known. Data used in the universal soil loss equation indicate the increasing soil organic matter from 1 to 3 percent can reduce erosion 20-33 percent because of increased water infiltration and stable soil aggregate formation caused by organic matter.

Soluble Salts

Soluble salts in the soil are measured on a 1:1 soil:water suspension or using a saturated paste method (SPM). The amount of electrical current this suspension conducts is an indicator of the total salt content of the soil. A soil with a high soluble salt content will conduct more electricity than a soil with a low salt content. The relative amount of soluble salt in a soil is reported as millimhos per centimeter (mmhos/cm). High soluble salt levels can decrease water uptake of growing plants, therefore, affecting the growth and germination of many crops. Soluble salts are mobile.

EC (1:1 soil;water) exceeding 0.50 mmhos/cm are damaging.

mmhos/cm		Description	Effect on Crop
1:1	SPM		
0-.25	0-2	Non-Saline	None
.25-.50	2-4	Slightly Saline	Sensitive Crop Restrictions
.50-1.0	4-8	Moderately Saline	Many Crop Restrictions
1.0-1.5	8-16	Strongly Saline	Most Crops are Restricted
>1.5	>16	Extremely Saline	Few Tolerant Crops

Crop Tolerance

Poor Tolerance	Average Tolerance	Good Tolerance
Soybeans Red Clover Green Beans	Wheat, Oats, Rye Corn, Sorghum Alfalfa, Sunflower Flax, many grasses	Barley Sugar Beets Rape Western Wheatgrass

Exchangeable Sodium

Sodium is extracted using ammonium acetate and is reported in ppm. Sodium is not a plant essential nutrient, but these levels are important for determining the CEC by summation. These levels also help establish excess amounts of sodium and whether they will have the potential to cause problems with soil structure.

Concentrations:

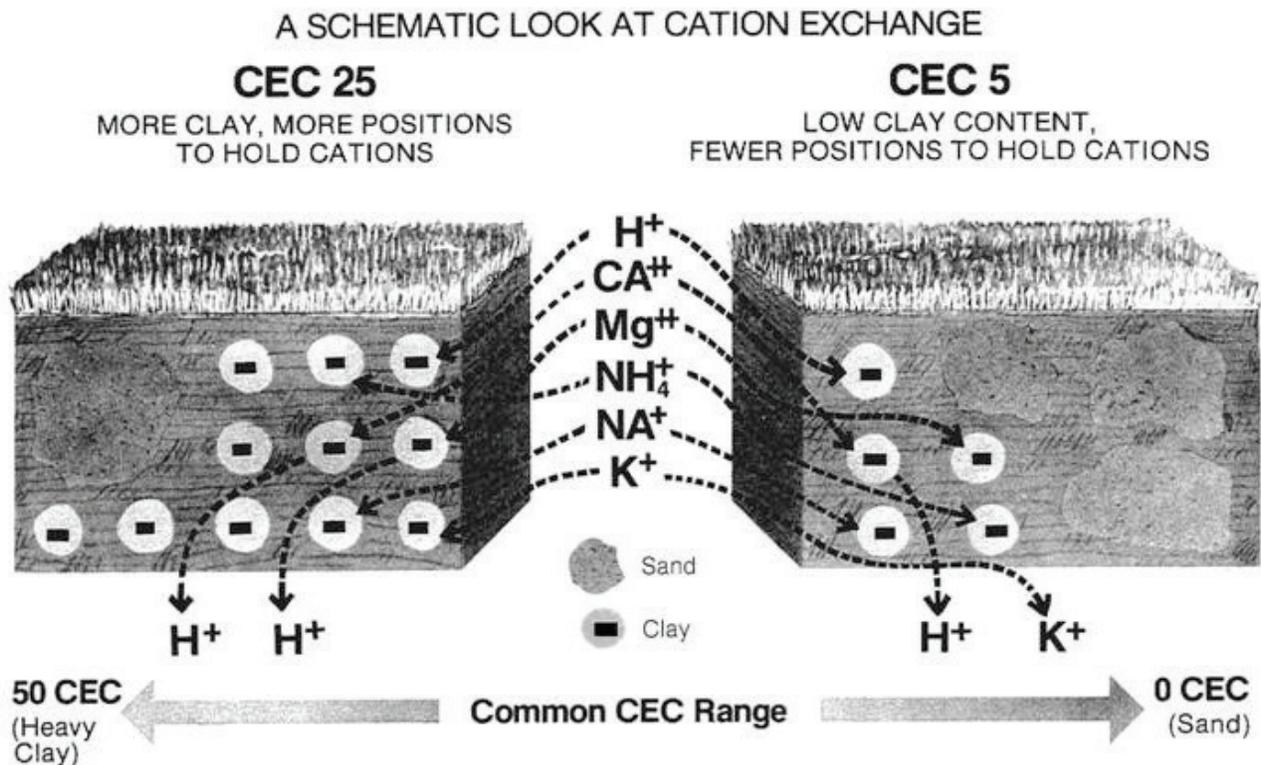
- **Very Low** (0-40 ppm)
- **Low** (41-80 ppm)
- **Medium** (81-120 ppm)
- **High** (121-160 ppm)
- **Very High** (161+ ppm)

Cation Exchange Capacity (CEC)

Soils are composed of a mixture of sand, silt, clay and organic matter. Both the soil and organic matter particles have a net negative charge. Thus, these negatively-charged soil particles will attract and hold positively-charged particles, much like the opposite poles of a magnet attract each other.

Cation Exchange Capacity measures the soil's ability to hold nutrients such as calcium, magnesium, and potassium, as well as other positively charged ions such as sodium and hydrogen. The CEC of a soil is dependent upon the amounts and types clay minerals and organic matter present. The common expression for CEC is in terms of millequivalents per 100 grams (meq/100g) of soil. The CEC of soil can range from less than 5 to 35 meq/100g for agricultural type soils. Soils with high CEC will generally have higher levels of clay and organic matter.

CEC is routinely determined by the summation method. This method is more accurate for soils that do not contain free calcium and magnesium, generally, associated with soils with a pH of 7.0 or greater. When high levels of free calcium and magnesium are present, the CEC's will appear higher and may provide inaccurate information for herbicide recommendations and other management decisions.



SOME PRACTICAL APPLICATIONS	
Soils with CEC 11-50 Range	Soils with CEC 1-10 Range
<ul style="list-style-type: none"> • High clay content • More lime required to correct a given pH • Greater capacity to hold nutrients in a given soil depth • Physical ramifications of a soil with a high clay content • High water-holding capacity 	<ul style="list-style-type: none"> • High sand content • Nitrogen and potassium leaching more likely • Less lime required to correct a given pH • Physical ramifications of a soil with a high sand content • Low water-holding capacity

Calculating CEC

K, meq/100g soil = ppm/acre extracted K ÷ 391

Mg, meq/100g soil = ppm/acre extracted Mg ÷ 120

Ca, meq/100g soil = ppm/acre extracted Ca ÷ 200

Na, meq/100g soil = ppm/acre extracted Na ÷ 230

CEC = total meq/100g of soil ... Add values from calculations above H + K + Mg + Ca + Na

Base Saturation

Base saturation refers to the proportion of the CEC occupied by a given cation (a positively charged ion such as calcium, magnesium, potassium, hydrogen, or sodium). This information gives us another tool to use in predicting the soils ability to provide adequate crop nutrients, and indicate needed changes in fertilizer or lime programs. A simplified example of percent saturation would be where a soil is capable of holding 100 cations and these 100 "exchange sites" are occupied by the following nutrients.

Calculating Base Saturation

$$\%BS\ K=(K\ meq/100g\ soil)/CEC$$

$$\%BS\ Ca=(Ca\ meq/100g\ soil)/CEC$$

$$\%BS\ Mg=(Mg\ meq/100g\ soil)/CEC$$

$$\%BS\ Na=(Na\ meq/100g\ soil)/CEC$$

The percentage of saturation for each of the cations will usually be within the following ranges:

Calcium **40-80 percent**

Magnesium **10-40 percent**

Potassium **1-5 percent**

Since a soil test report is typically not measuring and reporting all of the cations that are in the soil, it is common for the sum of the measured cations to add up to less than 100%. Also, when the soil pH is above about pH 7.2, the sum of the cation saturation's may add up to more than 100%. This is because there is likely to be "free" Ca, Mg, and/or Na (unattached to the soil exchange complex) in the soil that is unavoidably extracted by the soil testing process.

SAR (Sodium Adsorption Ratio)

The Sodium Adsorption Ratio (SAR) reflects the Na:Ca + Mg. As sodium levels increase, the calcium and magnesium cations are replaced. This reduces soil structure and is often observed by crusting and low water permeability.

SAR Ratio:

1-5 is considered low and non-damaging

6-10 is moderate and potentially damaging

>11 is damaging.

Other notes: High levels of sodium in the soil tend to flocculate (disperse soil particles), resulting in poor soil structure and low water infiltration. Since sodium is mobile, added calcium (gypsum) will displace sodium and allow it to leach out of the soil profile by way of irrigation water and/or rainfall. Soils high in calcium have better structure than those high in sodium. Use of gypsum on soils where sodium is not high has generally not been shown to be effective in improving soil structure.

Texture

Estimated texture is grouped into categories of coarse or medium/fine based on organic matter content. Peat is indicated if the organic matter level is greater than 20%. Precise texture determination can be made by measuring the percent sand, silt, and clay in the sample using the hydrometer method. Texture, along with organic matter content, is vital when determining rates for soil-applied herbicides.

Calcium Carbonate Equivalent (CCE)

Measures the total calcium (Ca) & magnesium (Mg) carbonates in the soil. Testing your fields for carbonates when the pH is above 7.2 and the soluble salts are above 0.3 mmhos/cm will improve your ability to manage iron chlorosis. Soils with pH below 7.2 can also have considerable free Ca and Mg carbonates.

- Sandy soils with low organic matter (<3.0%) and a high salt level (>1.0) have a higher risk of iron chlorosis than a loam or clay soil with the same level of carbonates and salt.
- The risk and severity of iron chlorosis will increase in years with excessive moisture.
- When CCE's are high, make sure the potassium (K) levels are in the very high range as well.
- Soils with a high level of carbonates may also require higher levels of phosphorous fertilizer due to phosphorous combining with calcium to form calcium phosphates with a low solubility.

Concentrations

- **Low** (0-2.5%)
- **Moderate** (2.6-5%)
- **High** (5.1-10%)
- **Very High** (10% +)

CCE and Soluble Salt Risk Levels

In the table below, increased Risk Level when CCE's are over 5%.

CCE	Soluble Salts	Risk Level
1-5%	0.3 – 0.4	Moderate
1-5%	0.5 – 0.6	High
1-5%	0.7 – 0.9	Very High
1-5%	1.0 – 1.50	Extremely High
1-5%	> 1.50	Not Suitable (Soybeans)



What are the 4Rs

4R Nutrient Stewardship provides a framework to achieve cropping system goals, such as increased production, increased farmer profitability, enhanced environmental protection and improved sustainability.

To achieve those goals, the 4R concept incorporates the:

- **Right fertilizer source at the**
- **Right rate, at the**
- **Right time and in the**
- **Right place**

Properly managed fertilizers support cropping systems that provide economic, social and environmental benefits. On the other hand, poorly managed nutrient applications can decrease profitability and increase nutrient losses, potentially degrading water and air.

4R nutrient stewardship requires the implementation of best management practices (BMPs) that optimize the efficiency of fertilizer use. The goal of fertilizer BMPs is to match nutrient supply with crop requirements and to minimize nutrient losses from fields. Selection of BMPs varies by location, and those chosen for a given farm are dependent on local soil and climatic conditions, crop, management conditions and other site specific factors.

Other agronomic and conservation practices, such as no-till farming and the use of cover crops, play a valuable role in supporting 4R nutrient stewardship. As a result, fertilizer BMPs are most effective when applied with other agronomic and conservation practices.



RIGHT SOURCE

Matches fertilizer type to crop needs.



RIGHT RATE

Matches amount of fertilizer type crop needs.



RIGHT TIME

Makes nutrients available when crops needs them.



RIGHT PLACE

Keep nutrients where crops can use them.



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