

## Section 9 of 22 (9g - Soil Fertility Interpretation)

# Essential and Beneficial Elements in Higher Plants

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H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt									
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb		
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No		

### Essential Mineral Elements:

- ✦ **Nitrogen (N):** is utilized by plants to synthesize amino acids, primary components of proteins. It is also required for chlorophyll and enzymes.
- ✦ **Phosphorus (P):** is present in all living cells. It is utilized by plant to form DNA and RNA, and is used in storage and transfer of chemical energy for growth and reproduction.
- ✦ **Potassium (K):** is needed for translocation of sugars and formation of starch. It is required in opening and closing of stomates. It promotes root growth and increases plant resistance to disease. It increases size and quality of fruits, nuts, grains, and vegetables and is necessary for high-quality forage crops.
- ✦ **Calcium (Ca):** is an essential part in cell walls and membranes and must be present for formation of new cells.
- ✦ **Magnesium (Mg):** serves as an activator of plant enzymes required in growth processes.
- ✦ **Sulfur (S):** is needed for amino acids and nodule formation on legume roots.

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<http://www.nm.nrcs.usda.gov/technical/handbooks/iwm/nmiwm.html> rudy.garcia.2009

- ✦ **Zinc (Zn):** controls the synthesis of indoleacetic acid, an important plant growth regulator, and is important to enzyme systems.
- ✦ **Iron (Fe):** is required for chlorophyll and is an activator for respiration, photosynthesis and symbiotic nitrogen fixation.
- ✦ **Manganese (Mn):** serves as an activator for enzymes. It assists iron in chlorophyll formation.
- ✦ **Copper (Cu):** serves as an activator of several plant enzymes.
- ✦ **Boron (B):** functions in plants in differentiation of meristematic cells. It is also involved in regulating metabolism of carbohydrates in plants. Boron toxicity is rare; usually associated with high levels of B in irrigation water.
- ✦ **Molybdenum (Mo):** is required by plants for utilization of nitrogen and for symbiotic fixation of nitrogen by legumes. High concentrations in forage can be toxic to livestock.
- ✦ **Chlorine (Cl):** is required in photosynthetic reactions in plants and is utilized in regulating cell turgor potential.
- ✦ **Nickel (Ni):** is required in very small amounts. It is a component of enzyme urease, for the conversion of urea to ammonia in plant tissue. It is important to overall nitrogen metabolism.

## Soil Test

- ✦ Is a chemical means of estimating the nutrient supplying power of the soil.
- ✦ Is a chemical indicator of soil quality.
- ✦ It is necessary that the test be calibrated before it can be properly interpreted.
- ✦ Soil tests are calibrated by establishing fertilizer rate experiments on different soils to determine the best fertilizer rate at a given soil test level. Land grant universities provide this type of information and recommendations.

## Soil Test Ratings

- ✦ Most soil test readings on the report are given a rating of very low (VL), Low (Low), Medium (M), High (H), and Very High (VH). This rating provides a general guideline for determining optimum nutrient level for crop growth.

## Organic Matter (OM)

- ✦ Colloidal humus (i.e., OM) is the by-product of microbially decomposed plant and animal residue. It is a reservoir of many plant nutrients (e.g., nutrients existing as structural components of organic matter such as nitrogen, phosphorus, and sulfur or existing as exchangeable cations).
- ✦ The typical range of OM found in irrigated & cultivated soil is generally between 0.8- 1.2 % (dry weight basis).
- ✦ The climate of the area, crop residue, soil type, fertility status, and management practices (e.g., extent of cultivation, irrigation, and use of animal waste) influences the amount present in the soil.
- ✦ Approximately 58% of the OM consists of organic carbon.
- ✦ OM helps strengthen soil aggregates, improving soil structure, soil tilth, aeration, water-holding capacity. OM influences nutrient availability, soil pH, and other major soil properties. It provides a food source for soil microorganisms.
- ✦ About 20 - 40 pounds of Organic Nitrogen (ON) is mineralized per acre per year for a soil containing 1% OM in the acre-furrow slice (i.e., about 0 - 6" depth). Most of this Nitrogen (N) is made plant-available during the growing season by microbial mineralization and nitrification. The amount mineralized is considered as part of the crop N requirement. About 2.5% of the total ON is mineralized per year.

## Cation Exchange Capacity (CEC)

- ✦ The CEC of a soil is based on the % and type of clay mineral (e.g., smectites, kaolinites, & sesquioxides) and % OM.
- ✦ The CEC is a measurement of the soils nutrient reservoir or buffering capacity of the soil.
- ✦ The negatively charged surfaces of these COLLOIDS have the cations of calcium, magnesium, potassium, ammonium, and sodium adsorbed on to it. These cations are readily exchanged with similar cations in the soil solution.
- ✦ In most calcareous soils, the CEC will range between 5-35 milliequivalents per 100 grams of soil (meq/100 g). e.g., it takes one milliequivalent of calcium ions (i.e., 20 mg of calcium) to displace exactly one milliequivalent of sodium ions (i.e., 23 mg of sodium). Low %O.M. and coarser texture soils have lower CECs and higher %O.M. and finer texture soils have higher CECs.

## Exchangeable Nutrient Cations

### (Potassium, Calcium, and Magnesium)

- ✦ The type and amount of clay and OM in the active root zone will determine the relative availability of these ions. These essential nutrients (elements) are given as parts per million (ppm) and the actual level analyzed is reported as being Very Low, Low, Medium, High, and Very High.
- ✦ Potassium, Calcium, and Magnesium nutrient responses are expected when

soil levels are Very Low and Low, which is usually associated with soils low in clay and organic matter (e.g., sandy loam, loamy sand, and sandy soils). However, for optimal crop production, soil levels should be maintained at or above the medium level in all soil types.

### Exchangeable Potassium ( $K^+$ )

- ✚ Potassium deficiency is most commonly associated with sandy soils. The optimal level will vary with crop, yield, and soil type. It is an immobile nutrient like phosphorus and levels change slowly. Potassium typically accounts for 2 - 8% of the CEC.

### Exchangeable Calcium ( $Ca^{2+}$ )

- ✚ Calcium deficiency is rare in most calcareous soil where soil pH is adequate. The need for calcium as a nutrient is directly related with soil pH. The level in the soil can exceed 4,000 ppm without evidence of excess in the plant. Calcium typically accounts for 70 - 85% of the CEC.

### Exchangeable Magnesium ( $Mg^{2+}$ )

- ✚ Most soils contain high levels of magnesium, therefore, yield response to magnesium fertilizer application are uncommon (exception on sandy soils with low CEC and OM).
- ✚ Magnesium typically accounts for 10 - 20% of the CEC.
- ✚ Magnesium deficiencies are more common than calcium.
- ✚ Some of the total soil magnesium is found in non-exchangeable form. Thus, the exchangeable magnesium level changes slowly with time because of equilibrium with minerals.

### Exchangeable Sodium Percent (ESP)

- ✚ High ESPs can cause high soil pH, sodium toxicity to sensitive plants, surface sealing, crusting, and drainage problems (reduced infiltration, permeability), nutrient imbalances/deficiencies. The lower the salinity, the more severe the problems (especially with  $EC_e < 1.0 - 0.5$  mmhos/cm).
- ✚ Where elevated levels are found, soil amendments such as gypsum or elemental sulfur are applied.
- ✚ An ESP value of 5 or less is desired, while values between 6 - 9 mean increasing problems with reduced infiltration/permeability, especially in clayey soils with low  $EC_e$  (i.e., low soil salinity). ESP values  $> 13$  generally mean severe problems for most soils (with the exception of sandy soils).

### Exchangeable Sodium ( $Na^+$ )

- ✚ This element is retained in the soil as an easily exchangeable cation, which at elevated levels (e.g., H and VH), can detrimentally influence the soil solution

- pH, nutrient balances, soil infiltration and permeability, and soil solution salinity levels.
- ✚ The presence of excess sodium is evaluated with the ESP.
  - ✚ Sodium is not considered an essential plant nutrient and consequently a VL and L value or range is desired.
  - ✚ Soil amendments such as gypsum and elemental sulfur can be used to reduce the amount of exchangeable sodium.
  - ✚ Actual amounts of soil amendments should be based on the ESP, exchangeable sodium ppm level to be reduced to, soil depth to be remediated, and product purity.
  - ✚ The sodium source can be poor irrigation water quality, poor water management, poorly drained clayey soils, excess manure applications, shallow water table, and poor drainage.
  - ✚ Sodium typically accounts for 3 - 10% of the CEC.

### Electrical Conductivity (ECe)

- ✚ The ECe value in millimhos per centimeter (mmhos/cm) reports the level of soluble salts which consist of cations (i.e., calcium, magnesium, and sodium, with minimal contribution coming from potassium) and anions (i.e., chloride, sulfate, and bicarbonate) in the soil solution.
- ✚ A value of 1 mmhos/cm is approximately equal to 640 mg/l of soluble salts.
- ✚ The ECe is an estimate of the soluble salts found in the soil solution; is a measurement taken of a soil saturation extract.
- ✚ Every crop has a level of soluble salts that it can tolerate (salinity threshold) in the soil solution, above which the plant will experience yield reduction.
- ✚ If the reported ECe value is above the plant threshold level, then leaching of soluble salts should be considered.
- ✚ Typically, the soil salinity level is between 1.5 - 3 times that of the irrigation water (surface irrigation ~1.5; drip/sprinkler ~ 3).
- ✚ Classification of salt-affected soils: Saline soils (ECe > 4 mmhos/cm, ESP < 15, and pH < 8.5). Saline-Sodic soils (ECe > 4 mmhos/cm, ESP >15, and pH < 8.5). Sodic soils (ECe < 4 mmhos/cm, ESP > 15, and pH >8.5 - 10).
- ✚ Used in evaluating the crop salt tolerance and yield reduction %. Above a determined salinity level, all crop yields begin to decline. Can produce water stress in a plant.

### Soil pH (H<sup>+</sup>)

- ✚ The pH indicates the activity of the soil solution (i.e., the hydrogen ion (H<sup>+</sup>) concentration), which regulates the solubility (availability) of micro nutrients and phosphorus to plant roots.
- ✚ Measures the degree of acidity or alkalinity (i.e., of a soil paste wet to saturation).
- ✚ A pH < 7.0 is acid, pH = 7.0 is neutral, and a pH > 7.0 is alkaline. A pH of 6.0 - 7.5 is optimum range for crop growth. A pH > 8.4 indicates a sodium problem.
- ✚ The normal pH range for calcareous soils, soils containing the mineral calcite (CaCO<sub>3</sub>), also referred to as lime, is generally between 7.7 to 8.5 or greater is typically due to a sodic soil condition (i.e., soils with elevated exchangeable

sodium) where the Exchangeable Sodium Percent (ESP) is > 13. However, an ESP lower than 13 can cause similar problems to a sodic soil if the soluble salts in the soil solution are low (e.g., where the E<sub>Ce</sub> is < 1.0 mmhos/cm).

### Free Lime (CaCO<sub>3</sub>)

- ✦ A yes answer means that the soil contains approximately 0.5 - 1% or greater finely-divided (i.e., extremely small particles) lime on a soil dry weight basis.
- ✦ Soils high in free lime tie up major and minor elements making them less available to the plant. The higher the lime, the more buffered is the soil pH.
- ✦ The lime will buffer the soil pH at approximately 7.7 - 8.3, depending on the equilibrium that exist between carbon dioxide gas (CO<sub>2</sub>) dissolved in the soil solution and the solubility of the lime.
- ✦ A yes answer is required if elemental sulfur or sulfuric acid soil amendments are to be used.
- ✦ Calcareous soils contain between 1 - 8% lime (calcium carbonate, CaCO<sub>3</sub>). This secondary mineral (i.e., calcite) is colloidal in size (i.e., very small particles with very low solubility). The actual amount determines the magnitude of soil pH buffering, e.g., a soil containing 1% free lime is approximately equal to 36,000 pounds of lime per acre-foot.
- ✦ Actual amounts influence phosphorus tie-up.

### Nitrate Nitrogen (NO<sub>3</sub><sup>-</sup>-N)

- ✦ The ppm nitrate-nitrogen multiplied by 3.6 will give the approximate pounds of nitrogen (i.e., units of N) per acre-foot, e.g., 20 ppm multiplied by 3.6 = 72 pounds of N per acre-foot.
- ✦ Nitrate is highly soluble, therefore, it is easily leached below the root zone.
- ✦ Nitrate is the dominant form of N found in the soil. Residual nitrate will satisfy a portion of the crop requirement.
- ✦ Split applications of fertilizer N will ensure optimal nitrogen uptake by the crop.
- ✦ All N sources are converted to nitrate. Nitrate is the end product of the N cycle.
- ✦ In well drained (aerated), moist, and warm soils (optimal soil condition for maximum plant productivity) all N forms will convert to nitrate in a relatively short time.
- ✦ Nitrate-Nitrogen is reported in ppm. 1 ppm of Nitrate-Nitrogen found per acre-foot of soil is approximately equal to 3.6 pounds of N or approximately 16 pounds of nitrogen in the form of nitrate (NO<sub>3</sub><sup>-</sup>).
- ✦ This available N should be considered at arriving at fertilizer recommendations based on crop N requirements.

### Bicarbonate Phosphorus (H<sub>2</sub>PO<sub>4</sub><sup>-</sup> & HPO<sub>4</sub><sup>2-</sup>)

- ✦ This value is the plant available phosphorus for soil with a pH > 7.0. Available/soluble P (i.e., orthophosphate, H<sub>2</sub>PO<sub>4</sub><sup>-</sup> and HPO<sub>4</sub><sup>2-</sup>) in the soil solution is in equilibrium with phosphate minerals (primarily calcium phosphate) which are the primary source/suppliers of P to the soil solution as

- soluble P is taken up the crop plant.
- ✦ Phosphorus is reported as ppm. As is reported for essential plant nutrients, the laboratory tested P value is given a rating characterized as Very Low, Low, Medium, High, and Very High.
- ✦ This test measures the relative amount of readily available P in soils with pH > 7.0. The actual amount cannot be measured. Test result and recommendation is based on % sufficiency.
- ✦ The recommendations given are based on the amount of P<sub>2</sub>O<sub>5</sub> required to achieve the expected yield for the given crop.
- ✦ The soil test result is only as estimate of the available P (the soil's ability to supply or buffer P in the soil solution).
- ✦ Fertilizer response is likely in the VL and L test levels.
- ✦ Is a non-mobile nutrient and is easily converted to unavailable forms in high pH and calcareous soils.

## Soil Texture

(% Sand, % Silt, % Clay, % Lime, & % Organic Matter)

- ✦ Coarse soils (Sand and Loamy Sand), Moderately Coarse (Sandy Loam and Fine Sandy Loam), Medium soils (Very Fine Sandy Loam, Loam, Silt, and Silt Loam), Moderately Fine soils (Sandy Clay Loam, Clay Loam, and Silty Clay Loam), and Fine soils (Sandy Clay, Silty Clay, and Clay).

## Sulfate-Sulfur (ppm)

- ✦ Sulfur deficiency is generally associated with sandy soils with low organic matter.
- ✦ Sulfate is leachable, similar to nitrate, but to a lesser extent.
- ✦ Some irrigation waters can supply most of the crop sulfur requirements. When irrigation water contains > 8 ppm, S fertilizer response is not likely.

Micronutrients (Nutrients that plants need in only small or trace amounts – Zn, Fe, Mn, Cu, B, Mo, Cl and Ni):

## Zinc (Zn)

- ✦ Zinc is the micronutrient most often deficient in western soils.
- ✦ Pecans, other tree crops, grapes, beans, onions, tomatoes, cotton, and corn have generally required zinc fertilization.
- ✦ Deficiency is most common on soils with neutral to high pH that are sandy or have low organic matter and very high in available phosphorus (Zn tied up with P).

## Iron (Fe)

- ✦ Iron deficiency can be induced by levels of available manganese or free lime in soils.
- ✦ Most of soil iron is unavailable to plants. Deficiencies are common in high pH soils, in situations with poor aeration, or when high levels of zinc or manganese are present.
- ✦ Crops most often affected are grasses, like corn and sorghum, alfalfa, some tree crops, and ornamentals.

## Manganese (Mn)

- ✦ High concentrations of manganese can induce iron deficiency.
- ✦ Some tree and high-yielding field crops may show deficiencies.

## Copper (Cu)

- ✦ Native soil copper is usually adequate for normal plant growth. However, copper deficiency has been observed on trees and vines and some annual plants growing in organic soils and sands.
- ✦ Copper can be toxic at low levels; its application is not recommended unless the soil test and land grant university shows the need.

## Boron (B)

- ✦ Intensive cropping and irrigation have caused boron deficiencies to become more common over a wide range of soil and climatic conditions.
- ✦ Crops in the west most often associated with boron deficiency are chile, alfalfa, sugarbeets, and nut crops.
- ✦ Although boron toxicity can occur, it is rare. Toxicities are usually associated with high levels of boron in irrigation water.

## Molybdenum (Mo)

- ✦ High concentrations of molybdenum in forage can be toxic to livestock.
- ✦ Molybdenum deficiencies in legumes have been reported in a number of western states.

## Chlorine (Cl)

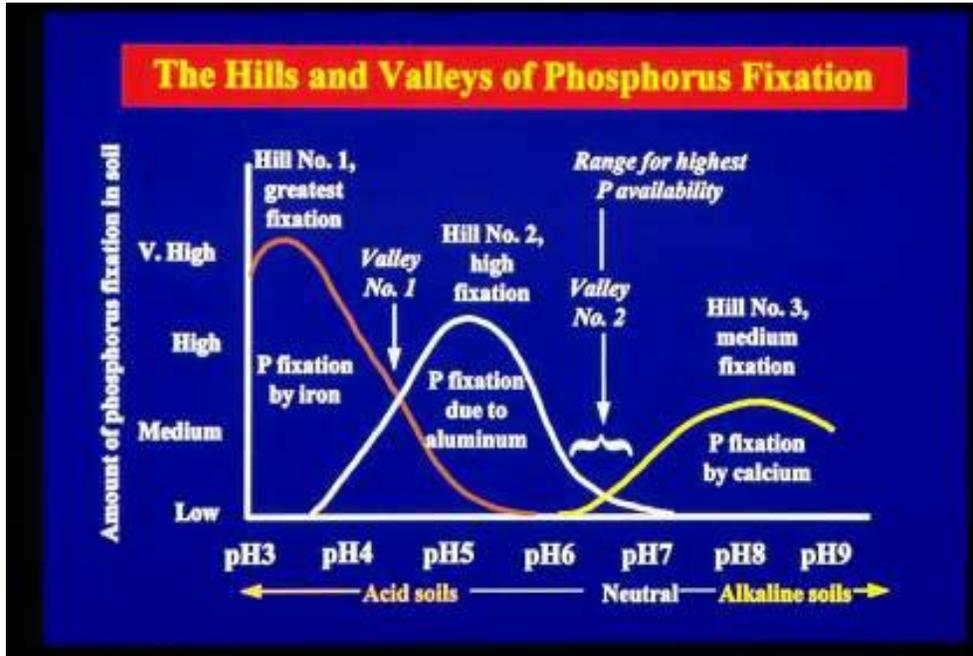
- ✦ Until mid-1980s, deficiencies of chloride in field were believed to be rare.
- ✦ However, it is required in plant photosynthesis and in regulating cells. It also helps increase disease resistance in many crops.
- ✦ Wheat, barley, and corn have benefited from chloride applications.

## Nickel (Ni)

- ✦ Nickel is important to overall nitrogen metabolism.
- ✦ It is required in very small amounts; the critical level in plant tissue is around 0.1 ppm; there have been no recorded deficiencies of nickel under any production conditions, so it not commercially monitored.

## Calculations

- ✚ An acre of mineral soil 6 to 7 inches deep (plow depth) weighs approximately 2 million pounds (i.e., dry weight). Thus, to convert parts per million (ppm) readings to pounds per acre of the elemental form, multiply by 2.



## Nutrient Availability with pH

