Soil Sampling

Soil sampling with Depth
Back hoe to 8 feet
Sample surface, 2, 4, 6 and 8 feet
Once every 10 years
Deep roots remove differential amounts of nutrients with depth
Analyze chemical and physical properties
Observe ease of root access at depths

Nutrients Required by Plants

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>C</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H</td>
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<tr>
<td>Oxygen</td>
<td>O</td>
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<tr>
<td>Nitrogen</td>
<td>N</td>
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<tr>
<td>Phosphorus</td>
<td>P</td>
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<tr>
<td>Potassium</td>
<td>K</td>
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<tr>
<td>Calcium</td>
<td>Ca</td>
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<tr>
<td>Magnesium</td>
<td>Mg</td>
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<tr>
<td>Sulfur</td>
<td>S</td>
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<tr>
<td>Iron</td>
<td>Fe</td>
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<tr>
<td>Manganese</td>
<td>Mn</td>
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<tr>
<td>Copper</td>
<td>Cu</td>
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<td>Zinc</td>
<td>Zn</td>
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<tr>
<td>Boron</td>
<td>B</td>
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<tr>
<td>Molybdenum</td>
<td>Mo</td>
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<tr>
<td>Chlorine</td>
<td>Cl</td>
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<tr>
<td>Nickel</td>
<td>Ni</td>
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<tr>
<td>Cobalt</td>
<td>Co</td>
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</tbody>
</table>

Carbon for Nutrition

Carbon (C) is derived from
Carbon Dioxide (CO2) in the air
Roots release and can absorb very small organic molecules
Sugars, amino acids and organic acids
Microbes surrounding roots absorb before roots can absorb the organic compounds
Nutrients are absorbed as non-organic form
Plants are about 41% Carbon by dry mass

Carbon Nutrition

Decomposition of crop residues and compost by soil microbes
Releases carbon dioxide gas
Application of lime (calcium carbonate or CaCO3) to an acidic soil
Releases carbon dioxide gas
Liming acidic soil is very slow
Wind brings new air supplying CO2 gas
**Hydrogen**

Hydrogen (H) is derived entirely from water (H₂O)
A hydrogen deficiency is technically the same as wilting
Water used by plants is biochemically
Separated by Photosystem II into
Oxygen (O₂) gas release plus
Hydrogen atoms used to make sugars

**Hydrogen**

Carbon binds to Hydrogen in plants
This Carbon – Hydrogen bonding is
A very high energy bond
This explains why crop residues can burn
Releases much of this high energy as heat
Sunlight is the source of the energy for the Carbon – Hydrogen bonds
Plants contain about 5 % H by dry mass

**Oxygen**

Oxygen (O) is obtained from several sources
Carbon dioxide (CO₂)
Water (H₂O)
Dioxygen (O₂) gas
Photosynthesis is represented by the process of plants using carbon dioxide splitting water and releasing oxygen

**Oxygen**

Photosynthesis

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow [\text{CH}_2\text{O}] + \text{O}_2 \]

Carbon Water Sugars Oxygen
Dioxide Carbohydrates

All plant cells conduct respiration

\[ [\text{CH}_2\text{O}] + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

Sugars Oxygen Carbon dioxide Water

**Oxygen**

Plant available Oxygen is a key problem for organic agriculture
Application of high amounts of crop residue or compost activates soil microbes
Causes high respiration in soil resulting in the consumption of Oxygen gas
Can create a deficiency of adequate Oxygen for plant root growth
Plants contain 46 % Oxygen by dry mass

**Nitrogen**

Nitrogen (N) is derived from the air
Dinitrogen (N₂) gas is 80 % of the air
Biological Nitrogen Fixation involves the various bacteria
Rhizobium, Bradyrhizobium, Sinorhizobium or Azorhizobium
In root nodules of legumes
Converts into Ammonium ($\text{NH}_4^+$)

**Nitrogen**
Microbial decomposition of crop residues or compost releases Ammonium ($\text{NH}_4^+$)
Term Nitrogen Mineralization is essential
Plants can use Ammonium, but the microbes usually consume it first
Nitrification is the microbial transformation of the Ammonium into Nitrate in the two step process

**Nitrification**

*Nitrosomonas and Nitrospira*

\[
\text{NH}_4^+ + \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{NO}_2^- + 2 \text{H}^+
\]
Ammonium Oxygen Water Nitrite 2 Acid ions

*Nitrobacter*

\[
\text{NO}_2^- + \text{O}_2 \rightarrow \text{NO}_3^- 
\]
Nitrite Oxygen Nitrate

Causes acidity to accumulate in soils
Requires Lime to correct this condition
Nitrate is easily soluble in water
Can Leach downward in the soil
Nitrate may accumulate at the bottom of the root zone
Late season root absorption of Nitrate from deep soil layer prolongs maturity

**Nitrogen Immobilization**
Ammonium is absorbed and incorporated into Amino Acids and Protein
Low Nitrogen plant residues encourage microbes to absorb Ammonium and Nitrate into the Microbial tissue
Immobilization is temporary
Creates Nitrogen deficiency in plants
Slowly releases Nitrogen as Ammonium

**Nitrogen Deficiency**
Delays maturity
Reduces crop quality
Makes the plants more susceptible to a wide variety of diseases
May not overcome in time to correct for this crop

**Nitrogen**
Non-legume plants contain about 1 % N
Legume plants contain about 3 % N by dry mass
Nitrogen must be released by microbial decomposition
Requires time for release
Most difficult management problem for organic agriculture

**Urea Nitrogen**
Urea decomposes by the Urease enzyme from bacteria (which requires Nickel Ni\(^{2+}\))
Forms Ammonia
Ammonia is a gas may volatilize into air
Causes major loss during composting
Ammonia immediately reacts with the soil water to form Ammonium
Ammonium is rapidly nitrified to Nitrate

**Electrical Neutrality for Plants**
Cations (+ charges) = Anions (- charges)
Potassium (K\(^+\)) = Nitrate (NO\(_3^-\))
All plants require K and N in large amounts
Amount of K nearly identical to N need
Amount used is about 10 times more than for Calcium, Magnesium, Phosphorus or Sulfur

**Nitrogen Use inside Plants**
Roots absorb Nitrate (NO\(_3^-\))
Leaves convert Nitrate into Ammonium (NH\(_4^+\))
Ammonium is very quickly converted into Amino Acids
Amino Acids are very quickly converted into plant protein
Amino Acids and Protein have 0 charge

**Organic Acid Production**
To provide electrical balance for the loss of negative charge from Nitrate absorption, the plant produces organic acids
Organic acids when manufactured have no electrical charge
Organic acids ionize into acidity (H\(^+\)) ions and Organic acid anions (- charge)

**Organic Acids**
<table>
<thead>
<tr>
<th>Organic Acid</th>
<th>Carboxylate ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxaloacetic acid</td>
<td>Oxaloacetate</td>
</tr>
<tr>
<td>Malic acid</td>
<td>Malate</td>
</tr>
<tr>
<td>Fumaric acid</td>
<td>Fumarate</td>
</tr>
<tr>
<td>Citric acid</td>
<td>Citrate</td>
</tr>
<tr>
<td>Tartaric acid</td>
<td>Tartarate</td>
</tr>
<tr>
<td>R-COOH</td>
<td>R-COO(^-)</td>
</tr>
</tbody>
</table>

**Nitrate Causes Organic Acids**
Nitrate (NO\(_3^-\)) conversion to protein caused plant to produce Organic acid anions (R-COO\(^-\)) to replace the lost negative charge of nitrate.
As the Organic acid anions accumulate, they release more H\(^+\) ions and pH drops.
Potassium ions go along for the ride.
K does **not** cause Organic Acid production
**Phosphorus**
Phosphate exists as either
- Dihydrogen Phosphate (H$_2$PO$_4^-$) at a pH less than 7
- Monohydrogen Phosphate (HPO$_4^{2-}$) at a pH greater than 7
Ideally, a pH of 6.5 optimizes the solubility of Phosphate
High lime soil has low available Phosphorus

**Phosphorus**
Plants contain 0.3 % P on dry mass basis
Organic agriculture is successful because it optimizes the amount of plant available Phosphorus in soil
This occurs for two reasons

**Phosphate Nutrition**
Organic residues decomposing
Paint over phosphate crystals
Microbial decomposition results in the formation of organic acids
Organic acids react with calcium phosphate crystals dissolve soluble phosphate
Maintains phosphate available longer

**Phosphate Nutrition**
Need to keep soil moist as with drip irrigation
More moisture maintains higher soluble and plant available phosphate
When soil dries to condition requiring irrigation, available phosphate has dropped to only 25 % of optimum moisture
Phosphate does not move in soil
P concentrates in the surface layer

**Potassium**
Potassium (K) exists as the Potassium ion (K$^+$)
Cations have a positive (+) electrical charge
Clay minerals and Humus have a negative (–) electrical charge
Called soil Cation Exchange Capacity (CEC) olds onto K$^+$ ion prevents leaching

**Potassium**
Plants contain about 1 % Potassium by dry mass
Adequate potassium is essential for the best quality of fruits and vegetables
Potassium sulfate from the Great Salt Lake is organically certified
Need to use more potassium for organic agricultural production

**Potassium**
Potassium (K$^+$) is mined to great depth
All crops remove K in large amounts from the soil
Harvesting and removal of crops removes many pounds of Potassium annually
K remains completely soluble
Only element completely soluble in water, soils and plants
Potassium

K concentrates in surface layer
Roots mine K with depth
Difficult to move K deeper into soil
K only moves 1 to 2 inches per year
When soil at surface becomes dry, crop absorbs almost no potassium
Need to replenish K to move deeper over time

Potassium

Sandy soils require 10 to 20 years
Clay soils require 40 to 50 years
To obtain any appreciable subsoil accumulation of potassium
Same is true for calcium and magnesium, but they are used in smaller quantities by the crop

Potassium on CEC

Does not assure plant absorption
Rate of K release from CEC to solution
Determines rate of K absorption by roots
Often this K release rate is too slow
Rate varies in sandy or clay soils
It varies with depth in the soil
K release rate remains constant for a soil

Potassium Release Test

Every 10 years conduct this test
Gives pounds of K per acre per day
Peak K need by plant
Week before and 2 weeks after bloom
Peak demand often 5 to 10 pounds of K per acre per day
Soils testing low K supply only 0.5 to 1 pounds of K per acre per day

Potassium

To correct a slow soil potassium release rate
Foliar Potassium fertilizer should be sprayed onto plant leaves near flowering
Potassium sulfate is the best choice
Avoid high application rate to prevent leaf burning

Potassium in plant

K is needed during early plant growth
K is stored in leaf tissue
Slow K movement in plants
Results in slow maturity
May not move K from leaves into fruit or grain at an effective rate
Results in poor crop quality
**Potassium’s role in Plant**
Potassium functions in activating the enzymes producing sugars in plant
Potassium squeezes enzymes to have the proper shape and make them work faster
Lack of potassium means shape is not optimum and only slow sugar production occurs
Brix development is very slow

**Luxury Consumption of K**
Grasses often have luxury consumption of K
Shallow roots absorb more K at surface and crop needs
K moves into plant vacuole
Usually K does **not** move out of vacuole
Luxury consumption seldom occurs for grapes with deep root systems and low K

**K Organic Acids and Acidity**
Net result is
\[ K^+ = \text{Organic Acid anions (R-COO')} = H^+ \]
The more Nitrate absorbed and converted into Protein by the plant, the more Organic Acids the plant forms
\[ K^+ = \text{NO}_3^- \text{ initially so } K^+ = \text{R-COO}' \]
More Organic Acids accumulated the lower the pH (H+ concentration increases)

**Buffering**
Organic acids may remain in the non-ionized state (R-COOH) or
They may ionize to the carboxylate ion form (R-COO\(^-\)) and release an H\(^+\) ion
This combination of ion forms creates a pH buffer system in the plant
Each Organic Acid has its own buffer pH

**Nitrogen and Potassium**
Nitrogen is the key to Organic acids and acidity in grapes, not potassium
It would be silly to reduce nitrogen fertilizer applications for grapes
Total leaf production requires adequate protein for sugar production
Starving the crop for potassium is just as silly

**Exchangeable Cations**
K\(^+\) is a Cation
Held on Cation Exchange Capacity CEC
CEC due to Clays and Humus
60 to 80 % Calcium Ca\(^{2+}\)
10 to 20 % Magnesium Mg\(^{2+}\)
3 to 6 % Potassium K\(^+\)
1 to 5 % Sodium Na\(^+\)
1 to 2 % Ammonium NH\(_4^+\)
Calcium

Calcium (Ca) exists as the Calcium ion \( \text{Ca}^{2+} \) as a Cation held on the CEC sites. Plants contain about 0.3% Ca in non-legumes and about 2% Ca in legumes on a dry mass basis. Most soils contain thousands of Calcium per acre. Need high soluble \( \text{Ca}^{2+} \) ions around roots.

Acidic Soils

May be low in Calcium
Apply lime (Calcium carbonate \( \text{CaCO}_3 \))
Corrects Calcium problem
Sandy soils often lower in Calcium than are clay soils
Calcium does not move very deeply
Calcium functions in binding cells together as Calcium pectates in cell walls

Calcium Builds Cell Walls

Calcium \( \text{Ca}^{2+} \) binds to pectates in cell walls forming strong bonds between plant cells
Berry skin can be weak opposite stem end
Berry splitting often due to low calcium
High potassium and magnesium with low calcium more often results in berry splitting

Calcium Deficiency

Results in blossom end rot
Difficult for \( \text{Ca}^{2+} \) ions to move from the stem to the blossom end
Low level of \( \text{Ca}^{2+} \) means cells not cemented together properly
Allows a wide variety of pathogenic bacteria and fungi to attack the weakened blossom end

Magnesium

Magnesium (Mg) exists as the Magnesium ion \( \text{Mg}^{2+} \) held on the CEC sites. Magnesium functions as the central ion of the Chlorophyll molecule. Plants contain about 0.3% Mg on a dry mass basis.

Magnesium

Excess Magnesium occurs in some local soils derived from serpentine rock or from dolomite lime.
Consider the Calcium / Magnesium ratio
Need about 5 times more Calcium than Magnesium
Problem soils often have 1 to 3 Calcium to Magnesium and need to apply Gypsum

Excess Magnesium

Delays maturity
Makes it difficult to develop sugars
Makes plant more susceptible to attack because \( \text{Ca}^{2+} \) can not form an adequate barrier of calcium pectate normally
Plants are exploited by a wide variety of plant pathogenic bacteria and fungi.
Gypsum

Gypsum is Calcium Sulfate Dihydrate as CaSO₄·2H₂O
Gypsum has an Electrical Conductivity of 2.2 mmhos/cm or 2.2 dS/m at saturation
Does not harm plants because it is only slightly soluble

Excess Gypsum

Excess Gypsum can cause an accumulation of sulfate
Sulfate induces a Molybdenum Deficiency
SO₄²⁻ is very similar to MoO₄²⁻
Causes a Nitrogen deficiency
Nitrate is absorbed to high concentrations
Plant can not convert nitrate into protein

Sulfur

Sulfur (S) exists mainly as the Sulfate (SO₄²⁻) ion
Anions have a negative (–) electrical charge
Anions being negative are repelled by the CEC (–) sites
Anions including Sulfate easily leach

Sulfur

Plants contain about 0.25 % S on a dry plant basis
Sulfur forms S–S bonds creating the proper shape for various proteins and especially enzymes
Low sulfur plants have yellow newly emerged leaves and exhibit slow growth
Encourages attack by plant pathogens

Sulfate

Organic sulfur in crop residues is slowly decomposed and converted into Sulfate
Plant roots absorb Sulfate (SO₄²⁻)
Need for sulfur is about 1 / 10 need for N
Plant converts Sulfate into Hydrogen Sulfide (H₂S) and quickly converts it into Amino Acids and Protein with 0 charge
Sulfate absorption makes Organic Acids

Nitrate and Sulfate

Plants can absorb more Nitrate and Sulfate than they need from the soil
When the protein need of the crop is met,
Additional Nitrate and Sulfate remain in these ion forms inside the plant
Organic Acid is not produced when the Nitrate and Sulfate ions accumulate in the leaf tissues and not used in metabolism

Break Time

Take 10 Minutes
Be attentive to the Information presented during this break!
Micronutrient Availability in Soil

Depends upon the water solubility
Ruehr’s rule
Soil pH determines the solubility of most Micronutrients
Solubility depends upon the electrical charge of the ion

Availability in Soils

Know the electrical charge
Plants and microbes use cations
Cations have a positive electrical charge
Most ions 2+, few 3+, some +1
Only elements used directly as elements:
Dioxygen gas (O₂)
Dinitrogen gas (N₂) used by nitrogen fixing bacteria in legume root nodules

Solubility of Ions in Soil Solution

Most metal micronutrients are 2+ ions
Iron Fe²⁺ Fe³⁺
Manganese Mn²⁺ Mn⁴⁺ (not soluble)
Copper Cu²⁺ Cu⁺ (very wet)
Zinc Zn²⁺
Nickel Ni²⁺
Cobalt Co²⁺ N₂ fixing bacteria

Solubility Rule

Metal 2+ ions
Solubility decreases $10^2 = 100$ fold
For each one unit increase in soil pH
Acidity from nitrification decrease pH
Sandy acidic soils may be pH 5.0
Liming a soil at pH 5 means
$10^2 \times 10^2 = 10^4 = 10,000$ fold less soluble metal 2+ at pH 7

Solubility of Metal ions in Soil

Metal ions with 3+ charge
Solubility decreases $10^3 = 1000$ fold for each unit increase in soil pH
Fe³⁺ and Al³⁺ are toxicity to plant roots and soil microorganisms
In a soil with a pH of 4
Al³⁺ solubility is $10^3 \times 10^3 \times 10^3 = 10^9 = 1$ billion times more soluble than at pH 7

Iron Solubility

Fe³⁺ becomes $10^3 = 1000$ fold less soluble with each unit increase in soil pH
In going from pH 6.3 to 8.3, Iron drops
$10^3 \times 10^3 = 10^6 = 1,000,000$ fold solubility
High Lime soil has CaCO₃ and pH 8.3
Iron is very commonly deficient
Exists as insoluble iron oxide rust

**Iron Transformations**

Microbes convert Iron between
Oxidized [ Fe³⁺ or Fe(III) form]
Reduced [ Fe²⁺ or Fe(II) form]
Microbes requires energy from decomposing crop residues to reduce Fe
Toxic Ferrous (Fe²⁺) iron in rice paddies
Common problem in poorly drained soils
Proper drainage and aeration avoids this

**Iron Function**

Ferric Iron (Fe³⁺) normally exists as
Iron oxide rust with low solubility
Root zone plants and microbes
Produce siderophores Natural chelates
Bind Fe³⁺ ions ideally six fold
Top and bottom Left and right
Front and back

**Iron Function**

Ferric Iron (Fe³⁺) is chelated inside plant Citrate (has 3⁻ charges)
Can bind iron with six fold chelation
Moves iron from roots to shoots
Citrate is part of the cell’s normal
Citric Acid or Tricarboxylic acid (3⁻) or Krebs Cycle

**Iron Function**

Iron binds to Sulfur forming a cage or in some circumstances a box of alternating Fe and S bonds in special proteins
Iron Sulfur complexes transfer electrons in plants
Need adequate sulfur amino acid cysteine
Is critical for transferring energy in the plants

**Iron Function**

Iron works in Cytochrome system to transfer electrons
Electrons are energy
Blood contains hemoglobin
Heme group binds to Iron (Fe²⁺)
Very similar to chlorophyll porphyrin ring binding to Magnesium (Mg²⁺)

**Iron Function**

Iron helps reduce:
Nitrate (NO₃⁻) to Nitrite (NO₂⁻) in plants
Sulfate (SO₄²⁻) to Sulfite (SO₃²⁻) in plants
Adds electrons (adds energy)
Enables plants to utilize both Nitrogen and Sulfur
Makes Amino Acids and Protein

**Iron Function**
In legume nodules Iron forms **Leghemoglobin (pink)** similar to blood hemoglobin
Binds strongly to Dioxygen gas (O₂)
Prevents Dioxygen gas poisoning of the
Nitrogenase enzyme produced by nitrogen fixing bacteria (**Rhizobium**)
Promotes adequate nitrogen fixation

**Manganese**
Exists as Mn⁴⁺ in MnO₂
Insoluble manganese oxides (Black rust)
Microbes reduce to soluble Mn²⁺
During a short period of high moisture
Rain or irrigation
Soluble Mn²⁺ accumulates temporarily
Reason seldom find Mn²⁺ deficient

**Manganese Function**
In plants Manganese is oxidized and reduced easily as Mn²⁺ ↔ Mn³⁺
Allows electron and energy transfer
Mn in photosynthesis
Mn in cell respiration
Mn²⁺ has key role in photosystem II
Releases Dioxygen gas (O₂) to air
Mn²⁺ may replace Magnesium Mg²⁺

**Manganese in Soil**
In some soils
Microbes oxidize Mn²⁺ to Mn⁴⁺
Microbes gain energy for cell growth
Causes Mn ions to become insoluble
Creates Mn deficiency in
Rhizosphere = region around plant roots
Makes plant susceptible to diseases

**Manganese Function**
Mn²⁺ assists in lignin synthesis along with Boron
Manganese concentration usually increases at site of plant pathogen attack
When Low manganese
Plants are more susceptible to diseases
Produce less phenolic compounds and lignin at site of attack
Copper

Copper is normally as Cu^{2+} [or Cu(II)]
Microbes reduce to Cu^{+} in very wet soils
Copper functions in oxidation reduction reactions (Redox)
Cu^{+} \rightarrow Cu^{2+}
Plastocyanin uses Cu during
Photosynthetic electron transport

Copper in Soil

Cu^{2+} binds extremely strongly to humus
99.9% of all Cu^{2+} is bound or chelated
In Histosols (Delta soils and drained swamps) often have copper deficiency
Note – Soil test may reflect adequate to high copper is an artifact of soil testing
Cu-Humus goes through filter is tested
High compost or residues may make Cu deficient

Copper in Soil

Cu^{2+} copper becomes 10^{2} =
100 less soluble as pH increases one unit
High lime soils (pH 8.3) may be deficient
California rocks & minerals low in copper
Veterinarians routinely inject copper into livestock
Plants have adequate Cu
Animals have insufficient Cu

Copper Function

Copper makes Lignin [woody tissue]
Cu deficient plants have weak stems
Often wilt more easily
More susceptible to plant pathogen attack
Develop male sterility
Causes poor seed set or fruit yield

Copper Level

Copper has very narrow range
Deficient to toxic
Copper deficiency symptoms
Difficult to diagnose in the field
Need regular soil and plant tissue tests to
Diagnose copper problems

Zinc

Zinc exists only as Zn^{2+}
Does not change Redox
California rocks and minerals are low in Zinc
Common reason for adding more zinc
$\text{Zn}^{2+}$ is $10^2 = 100$ times less soluble for each pH unit increase  
Zn deficiency common in high lime (pH 8.3) soils

**Zinc Interactions**

High phosphate level in soil  
Phosphate enters roots  
Prevents $\text{Zn}^{2+}$ moving from roots to shoots  
High phosphate fertilization  
Induces a Zinc deficiency  
Zn – Humus bond is strong  
May have low Zinc in high humus soils  
Zn-Humus filtered through in Zn soil test

**Zinc Function**

$\text{Zn}^{2+}$ is in carbonic anhydrase  
Converts carbon dioxide (CO$_2$) into carbonic acid (H$_2$CO$_3$)  
First step in photosynthesis  
Zn functions in the Hill Reaction  
Photosystem II releases Dioxygen gas (O$_2$)  
Zn in RNA polymerase regulates protein synthesis

**Zinc Function**

Zn helps form  
Indole Acetic Acid (IAA) hormone  
Promotes normal cell elongation  
Zn deficiency  
Leads to rosetting  
Lack of IAA hormone prevents normal elongation  
All leaves emerge at one point (rosetting)

**Nickel**

Ni$^{2+}$ is the central ion  
Urease enzyme  
Ni helps in disease resistance in plants  
Ni is in polyphenol oxidase  
Phenols repel insect and fungal pathogen attack at site of infection

**Cobalt**

Co$^{2+}$ is not known to be essential to plants  
Co$^{2+}$ is the central ion of Vitamin B$_{12}$  
Vitamin B$_{12}$ is made by Dinitrogen (N$_2$) fixing bacteria  
In legume root nodules  
Co is essential for abundant N$_2$ fixation
Legume Seeds

Often dusted with cobalt sulfate and Ammonium molybdate
Plus appropriate Rhizobium bacteria
Insures adequate cobalt and molybdenum for optimum nitrogen fixation in Alfalfa
*Rhizobium meliloti* fixes N₂ into NH₄⁺ (Ammonium) inside alfalfa root nodules

Sodium

Sodium is Na⁺
Na⁺ is essential for C₄ plants
Mainly tropical grasses
Usually not a problem
High sodium soils have salt problems
Need Gypsum and good quality irrigation water to Exchange and Leach sodium

Silicon

Silicon has no known essential role
Silicon concentrations in plants
Often 1 – 2 %
High in grasses forms biogenic opal
Causes animal’s teeth to wear away
Strengthens plant stems
Enhances fungal pathogen resistance in grasses

Molybdenum is odd

Metal ions are usually naked (have no oxygen surrounding them)
Molybdenum always has 4 oxygen atoms
Molybdate MoO₄²⁻

Ions with 2- are 10² = 100 times more soluble for each unit increase in soil pH

Molybdate Availability

Liming a soil with pH 5 to pH 7 raises
MoO₄²⁻ solubility 10² x 10² = 10⁴ = 10,000 times
Liming an acidic soil
Usually corrects a molybdenum problem
Without molybdenum addition

Molybdenum Deficiency

Often mask a Nitrogen (N) deficiency
Molybdenum functions in
Nitrate Reductase enzyme converts
Nitrate (NO₃⁻) into Nitrite (NO₂⁻)
Nitrite Reductase converts
Nitrite (NO₂⁻) into Ammonium (NH₄⁺)
Ammonium (NH₄⁺) is converted into Amino Acids then transformed into Proteins

**Molybdenum in Legumes**
Molybdenum is a Key atom in Nitrogenase
Functions in Dinitrogen fixing bacteria
Dinitrogen gas (N₂) into Ammonium (NH₄⁺)
Becomes Amino Acids and Protein
*Rhizobium, Bradyrhizobium, Sinorhizobium* and *Azorhizobium*
Produce Nitrogenase enzyme

**Molybdenum Deficiency**
Most common on acidic soils
Accentuated by high sulfate (SO₄²⁻)
Note similarity to molybdate ion (MoO₄²⁻)
Sulfate competes for molybdate absorption
Plants and microbes become deficient
Avoid excessive use of sulfate
Gypsum (CaSO₄·2H₂O calcium sulfate dihydrate) can aggravate molybdate deficiency

**Molybdenum Deficiency**
May occur on acidic sandy soils
Intensive vegetable production
*Brassica* develop “whiptail”
Nitrification produces strong acidity in sandy soils
Need to Lime
Avoid applying sulfate (Gypsum)

**Molybdenum Toxicity**
Molybdate is usually not toxic to plants
Animals eating alfalfa high in molybdate
Causes molybdenosis
Creates a copper deficiency in livestock
Ruminant livestock are often given a copper bolus in the stomach
Copper bolus slowly dissolves
Provides sufficient copper to overcome the excess Molybdate

**Molybdenum Toxicity**
Limited mainly to far Northeast CA and Nevada
Desert valleys with very high pH
Mainly irrigated alfalfa
No consideration for amending soils with copper
Plants appear normal in copper
Chlorine Availability

Chlorine is available as
Chloride (Cl\textsuperscript{-}) Anion
Anions are negatively charged ions (—)
Chloride forms a carbon-chlorine bond in
Compound functioning in
Photosynthetic pathway
One antibiotic produced by soil microbes
Contains a carbon-chlorine bond

Chloride Levels in Plants

Plants contain about 100 to 1000 times
More chloride than is essential
Wheat in Kansas has shown chloride deficiency
Growers use MgCl\textsubscript{2}
Why Kansas?
Greatest distance from any ocean
Sea breezes blow in NaCl sea salt
Rain rinses Chloride out of clouds

Chloride Function

Chloride provides good turgor pressure
Low chloride makes plants limp
Allows entry of plant pathogenic fungi
KCl (0-0-60) was used in early studies
Researchers confused role of K\textsuperscript{+}
with the role of Cl\textsuperscript{—}

Chloride Toxicity

Chloride can become toxic
Cl\textsuperscript{—} sensitive crops:
Avocados are extremely sensitive
Growing Avocados near ocean
Chloride salt burn on leaves
Berries often are easily burned by chloride
Potatoes develop starch granules with an abundance of water causes to rot easily

Chloride Toxicity

Chloride easily leached downward with appropriate amounts of good quality irrigation water
Must insure adequate drainage
Most chloride problems arise as major salt problems
Salts are mainly chloride and sulfate salts
Causes high Osmotic Pressure
Boron

Boron may exist as a trace contaminant of some soil minerals
Tourmaline is only major soil mineral
Very rare in soils
Older books claimed boron in soil existed as the tetraborate (B$_4$O$_7^{2-}$) ion
Only boric acid (H$_3$BO$_3^+$) exists in soils

Boric Acid (H$_3$BO$_3^+$) has a neutral electrical charge
Neutral charge has the same solubility at all pH values
The neutral charge means a low solubility in the solution
Reason it is very difficult to remove excess boron from a soil

Boron Ions

Boric Acid (H$_3$BO$_3^+$) can ionize at high pH
Can rearrange boric acid as B(OH)$_3^+$
Soil pH > 8.5
Abundance of hydroxide (OH$^-$) exists
Forms B(OH)$_4^{--}$
Solubility rule is a -1 charged ion is
$10^1 = 10$ times more soluble for each unit increase in soil pH

High Boron Soils

Only a few crops can tolerate high boron
Cotton is particularly tolerant of high boron
Boron accumulates in soils lacking drainage
Organic acid treatment of soil
Open pores and dissolve lime
Reduces boron ion B(OH)$_4^{--}$ solubility to boric acid (H$_3$BO$_3^+$) decreasing leaching

Boron Function

Boron has a key role in pollen viability
B / Ca ratio is critical for pollen
Boron helps form better cell walls
Calcium binds cell walls across cells
B / Ca ratio is a key to understanding the overall integrity of cell walls and root growth

Boron Function

Boron helps convert sugars
Into uronic acids
Normal sugars are alcohol groups
Alcohol is C-OH
Normal sugars for 6 atom ring with 5 Carbon and 1 Oxygen in the ring
This leaves 1 Carbon alone at the top
Boron Function
The lone Carbon alcohol is the normal sugar form
Uronic acids have lone Carbon converted from an alcohol into a carboxylic acid (COOH)
The cell wall binding occurs when this carboxylic acid loses a Hydrogen ion
Forms carboxylate ion (COO−)

Boron Function
Carboxylate ion (COO−)
Binds with Calcium (Ca2+)
Cell wall formation occurs by
Cell 1 Carboxylate (COO−)   (COO−)
  Ca2+    Ca2+
Cell 2 Carboxylate (COO−)   (COO−)
Strength of binding is critical to growth

Boron Function
Boron is a key element in lignification
Pathway to make phenolic compounds
Phenols are benzene ring groups
Lignin consists of phenols with 3 carbon propane heads
Lignin is the major woody tissue of plants

Boron Function
Each plant species makes a different form of lignin
Lignin consists of 10 to 50+ phenyl propane units linked head to tail
Each phenol has 3 separate link points
Phenols make plants more repellant to
Plant pathogens
Low boron plants are more susceptible to diseases

Boron Function
Low boron results in poor internal tissue development
Black heart in heads of lettuce
Heart rot in sugar beets
Storage roots of celery deteriorate
Internal cork develops inside apples
Citrus has thick peel with poor pulp

Thank You!
Remember our true hour together.
Contact me at
truehr@calpoly.edu