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**Macro- and Micro-Nutrient Management in Relation to Pest Control for Organic Systems**

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**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**

Carbon	C	Iron	Fe
Hydrogen	H	Manganese	Mn
Oxygen	O	Copper	Cu
Nitrogen	N	Zinc	Zn
Phosphorus	P	Boron	B
Potassium	K	Molybdenum	Mo
Calcium	Ca	Chlorine	Cl
Magnesium	Mg	Nickel	Ni
Sulfur	S	Cobalt	Co

**Carbon for Nutrition**

Carbon ( C ) is derived from

Carbon Dioxide (CO<sub>2</sub>) 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 CaCO<sub>3</sub>) to an acidic soil

Releases carbon dioxide gas

Liming acidic soil is very slow

Wind brings new air supplying CO<sub>2</sub> gas

### Hydrogen

Hydrogen (H) is derived entirely from water (H<sub>2</sub>O)  
A hydrogen deficiency is technically the same as wilting  
Water used by plants is biochemically  
Separated by Photosystem II into  
Oxygen (O<sub>2</sub>) 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 ( CO<sub>2</sub> )  
Water (H<sub>2</sub>O)  
Dioxygen ( O<sub>2</sub> ) gas  
Photosynthesis is represented by the process of plants using carbon dioxide splitting water and releasing oxygen

### Oxygen

Photosynthesis  
$$\text{CO}_2 + \text{H}_2\text{O} \longrightarrow [\text{CH}_2\text{O}] + \text{O}_2$$
  
Carbon                      Water                      Sugars                      Oxygen  
Dioxide    Carbohydrates

All plant cells conduct respiration  
$$[\text{CH}_2\text{O}] + \text{O}_2 \longrightarrow \text{CO}_2 + \text{H}_2\text{O}$$
  
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 ( N<sub>2</sub> ) 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 (  $\text{NH}_4^+$  )

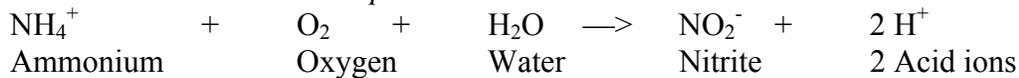
Term Nitrogen Mineralization is essential

Plants can use Ammonium, but the microbes usually consume it first

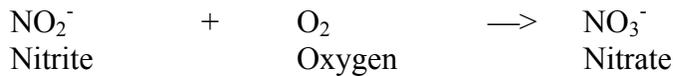
Nitrification is the microbial transformation of the Ammonium into Nitrate in the two step process

### **Nitrification**

*Nitrosomonas* and *Nitrosospira*



*Nitrobacter*



### **Nitrification**

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**

Organic Acid	Carboxylate ion
Oxaloacetic acid	Oxaloacetate
Malic acid	Malate
Fumaric acid	Fumarate
Citric acid	Citrate
Tartaric acid	Tartarate
R-COOH	R-COO <sup>-</sup>

### **Nitrate Causes Organic Acids**

Nitrate ( $NO_3^-$ ) conversion to protein caused plant to produce Organic acid anions (R-COO<sup>-</sup>) 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 ( $\text{H}_2\text{PO}_4^-$ ) at a pH less than 7  
Monohydrogen Phosphate ( $\text{HPO}_4^{2-}$ ) 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 dissolves 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 (  $\text{K}^+$  )  
Cations have a positive (+) electrical charge  
Clay minerals and Humus have a negative ( - ) electrical charge  
Called soil Cation Exchange Capacity (CEC) olds onto  $\text{K}^+$  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 ( $\text{K}^+$ ) 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  
 $K^+ = NO_3^-$  initially so  $K^+ = R-COO^-$   
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<sup>-</sup>) and release an H<sup>+</sup> 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  
 $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

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  
 $\text{SO}_4^{2-}$  is very similar to  $\text{MoO}_4^{2-}$   
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 ( $\text{SO}_4^{2-}$ ) 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 ( $\text{SO}_4^{2-}$ )  
Need for sulfur is about 1 / 10 need for N  
Plant converts Sulfate into Hydrogen Sulfide ( $\text{H}_2\text{S}$ ) 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 (O<sub>2</sub>)

Dinitrogen gas (N<sub>2</sub>) used by nitrogen fixing bacteria in legume root nodules

## Solubility of Ions in Soil Solution

Most metal micronutrients are 2+ ions

Iron	Fe <sup>2+</sup>	Fe <sup>3+</sup>
Manganese	Mn <sup>2+</sup>	Mn <sup>4+</sup> (not soluble)
Copper	Cu <sup>2+</sup>	Cu <sup>+</sup> (very wet)
Zinc	Zn <sup>2+</sup>	
Nickel	Ni <sup>2+</sup>	
Cobalt	Co <sup>2+</sup>	N <sub>2</sub> 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

Fe<sup>3+</sup> and Al<sup>3+</sup> are toxicity to plant roots and soil microorganisms

In a soil with a pH of 4

$$\text{Al}^{3+} \text{ solubility is } 10^3 \times 10^3 \times 10^3 = 10^9 =$$

1 billion times more soluble than at pH 7

## Iron Solubility

Fe<sup>3+</sup> 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

$$10^3 \times 10^3 = 10^6 = 1,000,000 \text{ fold solubility}$$

High Lime soil has  $\text{CaCO}_3$  and pH 8.3  
Iron is very commonly deficient  
Exists as insoluble iron oxide rust

### **Iron Transformations**

Microbes convert Iron between  
Oxidized [  $\text{Fe}^{3+}$  or Fe(III) form]  
Reduced [  $\text{Fe}^{2+}$  or Fe(II) form]  
Microbes requires energy from decomposing crop residues to reduce Fe  
Toxic Ferrous ( $\text{Fe}^{2+}$ ) iron in rice paddies  
Common problem in poorly drained soils  
Proper drainage and aeration avoids this

### **Iron Function**

Ferric Iron ( $\text{Fe}^{3+}$ ) normally exists as  
Iron oxide rust with low solubility  
Root zone plants and microbes  
Produce siderophores      Natural chelates  
Bind  $\text{Fe}^{3+}$  ions ideally six fold  
Top and bottom              Left and right  
   Front and back

### **Iron Function**

Ferric Iron ( $\text{Fe}^{3+}$ ) is chelated inside plant Citrate (has 3<sup>-</sup> 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<sup>-</sup>) 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 ( $\text{Fe}^{2+}$ )  
Very similar to chlorophyll porphyrin ring binding to Magnesium ( $\text{Mg}^{2+}$ )

### **Iron Function**

Iron helps reduce:  
Nitrate ( $\text{NO}_3^-$ ) to Nitrite ( $\text{NO}_2^-$ ) in plants

Sulfate ( $\text{SO}_4^{2-}$ ) to Sulfite ( $\text{SO}_3^{2-}$ ) 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 ( $\text{O}_2$ )  
Prevents Dioxygen gas poisoning of the  
Nitrogenase enzyme produced by nitrogen fixing bacteria (*Rhizobium*)  
Promotes adequate nitrogen fixation

### **Manganese**

Exists as  $\text{Mn}^{4+}$  in  $\text{MnO}_2$   
Insoluble manganese oxides (Black rust)  
Microbes reduce to soluble  $\text{Mn}^{2+}$   
During a short period of high moisture  
Rain or irrigation  
Soluble  $\text{Mn}^{2+}$  accumulates temporarily  
Reason seldom find  $\text{Mn}^{2+}$  deficient

### **Manganese Function**

In plants Manganese is oxidized and reduced easily as  $\text{Mn}^{2+} \leftarrow \rightarrow \text{Mn}^{3+}$   
Allows electron and energy transfer  
Mn in photosynthesis  
Mn in cell respiration  
 $\text{Mn}^{2+}$  has key role in photosystem II  
Releases Dioxygen gas ( $\text{O}_2$ ) to air  
 $\text{Mn}^{2+}$  may replace Magnesium  $\text{Mg}^{2+}$

### **Manganese in Soil**

In some soils  
Microbes oxidize  $\text{Mn}^{2+}$  to  $\text{Mn}^{4+}$   
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**

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

## Copper in Soil

$\text{Cu}^{2+}$  binds extremely strongly to humus  
99.9 % of all  $\text{Cu}^{2+}$  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

$\text{Cu}^{2+}$  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  $\text{Zn}^{2+}$   
Does **not** change Redox  
California rocks and minerals are low in Zinc  
Common reason for adding more zinc

$Zn^{2+}$  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  $Zn^{2+}$  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**

$Zn^{2+}$  is in carbonic anhydrase  
Converts carbon dioxide ( $CO_2$ ) into carbonic acid ( $H_2CO_3$ )  
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**

Nickel exists as  $Ni^{2+}$   
 $Ni^{2+}$  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**

Cobalt exists as  $Co^{2+}$   
 $Co^{2+}$  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  $N_2$  into  $NH_4^+$  (Ammonium) inside alfalfa root nodules

### **Sodium**

Sodium is  $Na^+$   
 $Na^+$  is essential for  $C_4$  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  $MoO_4^{2-}$

Ions with 2- are  $10^2 = 100$  times **more** soluble for each unit **increase** in soil pH

### **Molybdate Availability**

Liming a soil with pH 5 to pH 7 raises  
 $MoO_4^{2-}$  solubility  $10^2 \times 10^2 = 10^4 =$   
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 ( $NO_3^-$ ) into Nitrite ( $NO_2^-$ )  
Nitrite Reductase converts  
Nitrite ( $NO_2^-$ ) into Ammonium ( $NH_4^+$ )

Ammonium ( $\text{NH}_4^+$ ) 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 ( $\text{N}_2$ ) into Ammonium ( $\text{NH}_4^+$ )

Becomes Amino Acids and Protein

*Rhizobium*, *Bradyrhizobium*, *Sinorhizobium* and *Azorhizobium*

Produce Nitrogenase enzyme

### **Molybdenum Deficiency**

Most common on acidic soils

Accentuated by high sulfate ( $\text{SO}_4^{2-}$ )

Note similarity to molybdate ion ( $\text{MoO}_4^{2-}$ )

Sulfate competes for molybdate absorption

Plants and microbes become deficient

Avoid excessive use of sulfate

Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$  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<sup>-</sup>) 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<sub>2</sub>  
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<sup>+</sup>  
with the role of Cl<sup>-</sup>

### **Chloride Toxicity**

Chloride can become toxic  
Cl 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 ( $B_4O_7^{2-}$ ) ion  
Only boric acid ( $H_3BO_3^0$ ) exists in soils

### **Boron**

Boric Acid ( $H_3BO_3^0$ ) 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 ( $H_3BO_3^0$ ) can ionize at high pH  
Can rearrange boric acid as  $B(OH)_3^0$   
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 ( $H_3BO_3^0$ ) 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

