Soil Micronutrients

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SOMERSET COUNTY EXTENSION
What is an essential element?

• A nutrient that is required for plant growth
  – omission will cause death or abnormal growth

• Must not be replaceable by another element
Plant Nutrients – from soil

• PRIMARY nutrients: Nitrogen, Phosphorus and Potassium
  – N-P-K (10-10-10) fertilizers

• SECONDARY nutrients: Calcium (Ca), Magnesium (Mg) and Sulfur (SO4)
  – Lime, gypsum, sulfur fertilizers

• MICRO-nutrients: Boron (B), Chlorine (Cl), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), and Zinc (Zn)
What is a micronutrient?

- An essential element
- Found in less than 0.01% of the plant dry matter
Plant Nutrients – not from soil

- Carbon (C) – From CO$_2$ – At least half of the dry tissue is carbon
- Hydrogen (H) – From water
- Oxygen (O) – From water and air

80% of the plant is water
Average Concentrations in Plant Dry Matter Sufficient for Growth (Jones, 2012)

<table>
<thead>
<tr>
<th>Element</th>
<th>Concentration (mmol/g)</th>
<th>#atoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molybdenum</td>
<td>0.001</td>
<td>1</td>
</tr>
<tr>
<td>Copper</td>
<td>0.10</td>
<td>100</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.30</td>
<td>300</td>
</tr>
<tr>
<td>Manganese</td>
<td>1.0</td>
<td>1000</td>
</tr>
<tr>
<td>Iron</td>
<td>2.0</td>
<td>2000</td>
</tr>
<tr>
<td>Boron</td>
<td>2.0</td>
<td>2000</td>
</tr>
<tr>
<td>Chlorine</td>
<td>3.0</td>
<td>3000</td>
</tr>
<tr>
<td>Magnesium</td>
<td>80</td>
<td>80000</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>60</td>
<td>60000</td>
</tr>
<tr>
<td>Calcium</td>
<td>125</td>
<td>125000</td>
</tr>
<tr>
<td>Potassium</td>
<td>250</td>
<td>250000</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1000</td>
<td>1000000</td>
</tr>
</tbody>
</table>

You need 1000x more N than Mn
Boron – some important plant functions

• Only non-metal among the micronutrients
• Important in cellular functions
• Essential for pollen germination and growth
• Essential for seed and cell wall formation
Chlorine – some important plant functions

- Essential for photosynthesis (chlorotic tissues)
- Effects stomatal regulation
- Raises cell osmotic potential
Copper – some important plant functions

• Constituent of oxidase enzymes
• Metal component of some proteins (helps with electron transfer)
Iron – some important plant functions

• Important for electron transport in some enzymes

• Associated with enzymes in chlorophyll formation
Manganese – some important plant functions

• Involved in oxidation/reduction in photosynthesis
• Constituent of respiratory enzymes
• Accelerates germination and maturity
• Indirectly related to chlorophyll formation
Molybdenum – some important plant functions

• Very important to the plant if form of Nitrogen be taken up is nitrate ($\text{NO}_3^-$) helps convert it to ammonium ($\text{NH}_4^+$)

• Important component of legume nodules
Zinc – some important plant functions

• Needed for producing chlorophyll

• Aids in plant growth

• Improves root development, flowering and fruit production
Sources of Micronutrients

- Parent Materials (what the soil formed from)
  - Bedrocks can be nutrient rich, sediments may be nutrient poor
  - Rock type can be important (quartz has less micronutrients than granite)
Sources of Micronutrients

- **Organic Matter and Fertilizers** – from dead plant tissues or manure application
Location of Micronutrients Within the Soil

• Cation Exchange (soil surfaces)
  – Clay has greater CEC than sand!

• Organic Matter

• Solid Minerals (clays, oxides, ect)
  – pH become important!
Micronutrients can be held and exchanged off the soil, just like K, Ca or Mg.
Organic Matter

- Organic matter is very complex
- It may breakdown and release micronutrients
- It may hold micronutrients on its CEC
- It may chelate micronutrients making them more or less available
Soil Organic Matter and Micronutrients

• Breakdown of organic residues adds micronutrients

• Residues may also produce compounds that increase availability (chelate)

• Or decrease availability (Mn)
Solid Minerals: Often controlled by pH or reduction

For example: at lower pH Fe minerals that coat soil surfaces will dissolve and release free Fe (pH < 5.0)

Or saturated soils or enzymes may reduce red Fe$^{3+}$ to soluble/non-visible Fe$^{2+}$
Soil pH and Micronutrients

- A very important quick measure of availability!

- Only Mo becomes more available as pH rises (ignoring B above 8.5)
Soil pH and Micronutrients

• The reasons are complex

• In some cases they become solid minerals
  *$\text{Cu(OH)}_2$ instead of $\text{Cu}^{+2}$
  – Plants take up ions

• They may absorb to sites on soil minerals and organic matter
Soil reduction state and Micronutrients

- Reduction – $\text{Fe}^{+3}$ is “reduced” to $\text{Fe}^{+2}$ by adding an electron
  - Occurs in saturated soils

- Mostly affects Fe and Mn, making them more available.

- But who wants saturated soils for most crops?
Where are soils usually high in micros?

- Igneous parent material or other rocks high in nutrients

- Clay soils with high CEC or micronutrients in the mineral structure

- Soils with high organic matter (that provide micronutrients through breakdown)
Where are soils usually low in micros?

- Parent materials low in micronutrients – sandstones, alluvial sandy soils
- Weathered acid soils – where leaching has removed micronutrients
- Sandy soils with low CEC and low micronutrients in the mineral structures
- Organic matter with insoluble humin material that chelates metals and makes them unavailable (no silver bullet!)
How do plants obtain micronutrients?

• Root intercept – good pore space allows roots to explore (especially Mn)

• Water (mass) flow – nutrients move with moving pore water (B, Cl, Fe, Mo, Zn)

• Diffusion – nutrients move from high to low concentration (B, Cu, Fe, Mn, Mo, Zn)
Boron – In the Soil

• Typically in organic residues, released through decomposition

• Found as anion $\text{BO}_3^-$ or $\text{B(OH)}_3$ in soil water (for uptake)

• This form leaches easily since soils are negatively charged
Chlorine – In the Soil

• Often the matching anion salt (Cl-) to soil cations (think KCl)

• Negative charge means it doesn’t absorb to soil, so it moves with water flow

• Leaches, but soils must have a balanced charge
Copper – In the Soil

• Often bonded (complexed) to organic soil molecules like humic and fulvic acids
  – Plant roots may increase this process

• Doesn’t move with mass flow (water movement)
  – Strongly bonds to soil particles and doesn’t move

• Sandy and organic soils are more likely to be deficient
Iron – In the Soil

• Present as either Fe$^{+2}$ or Fe$^{+3}$ (red rust color)

• Fe$^{+2}$ is easier for plants to take up, they may release compounds to enhance availability

• Most Fe is in an insoluble form, organic molecules account for most movement in soils
Manganese – In the Soil

• Found as Mn$^{+2}$, Mn$^{+3}$ and Mn$^{+4}$
• Plants take up Mn$^{+2}$ (reduced form)
• Most Mn$^{+3}$ and Mn$^{+4}$ are solid minerals
• Can bond to organic matter and prevent uptake
  – 80 – 90% of Mn may be complexed with organic matter
Molybdenum – In the Soil

• $\text{MoO}_4^{-2}$ is an anion, so it leaches from soil easily

• Absorbs to iron and aluminum oxides
Zinc – In the Soil

• $\text{Zn}^{+2}$, on the soil exchange or complexed with organic matter
Summary of Micronutrient Forms

• **ANIONS** – B, Mo – so more likely to leach

• **CATIONS** – Cu, Fe, Mn, Zn – may associate with CEC, oxides or organic matter
Boron – Recognizing Deficiency

- Poor seed or fruit set
- Breakdown of growing tip tissue
- Leaves have scorched appearance
Copper – Recognizing Deficiency

• More likely in organic and sandy soils

• Copper isn’t mobile: stunted growth of new leaves
Iron – Recognizing Deficiency

• Immobile within the plant

• Interverinal chlorosis of younger leaves
Manganese – Recognizing Deficiency

• Immobile in the plant

• Interverinal chlorosis of younger leaves

• More likely on our soil types than Fe
Molybdenum – Recognizing Deficiency

• Yellowing of leaves similar to N
• Starts in older leaves first
• More likely in soil with pH < 5.5
Zinc – In the Soil

• Interveinal chlorosis on younger leaves – can be yellow or white

• White bud – younger buds turn white
Figure 4  Areas with zinc deficiency at the world scale (Source: Alloway 2008).
## Nutrient Mobility within the Plant

<table>
<thead>
<tr>
<th>Mobile</th>
<th>Immobile</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_3$</td>
<td>Ca</td>
</tr>
<tr>
<td>P</td>
<td>S</td>
</tr>
<tr>
<td>K</td>
<td>Fe</td>
</tr>
<tr>
<td>Mg</td>
<td>B</td>
</tr>
<tr>
<td>Cl</td>
<td>Cu</td>
</tr>
<tr>
<td>Zn</td>
<td></td>
</tr>
<tr>
<td>Mo</td>
<td></td>
</tr>
</tbody>
</table>
Nutrient Mobility in the Plant

Deficient in:

Fe, B and Cu
Ca, S

Mg, Cl, Zn, Mo
N, P, K

These nutrients are mobile, so they move to new tissue
Plant toxicity is also an issue

• Due to over application – Boron, Copper, Chlorine (fertilizer salts)

• Due to pH and soil concentrations or sludge additions–
  – Fe and Zn: pH < 5
  – Mn: pH < 5.5

• Plants are tolerant of Mo, but animals may not be
Interaction with other nutrients

• Most elements interact with each other. This list is not exhaustive, but be aware of how complex it can be:

  – Excess Mn may limit Fe uptake and vice versa

  – Higher levels of Ca limit Fe uptake

  – Cu has competitively limited Zn uptake

  – Zn has improved uptake of N, Mg and Cu
Pesticide applications can cause damage

- Other interactions may occur
- Pesticide damage may prevent nutrient uptake and mimic
- Dry soils will prevent nutrient uptake
Managing Micronutrients

• Soil Testing
  – More likely to have deficiencies on sandy and organic soils!
  – Basic soil test does N-P-K, more expensive test will include micronutrients

• Plant Tissue Testing
  – When you can’t figure out stunted plant growth or you see deficiency signs
Applying Micronutrients

• **Broadcast** – since you need so little, not always the best option
  – Most application rates are <10 lb/acre, more difficult to be even
  – Can be mixed with granulated or liquid, also coated granules

• **Banding** – place along side the plant where roots can reach it

• **Foliar** – apply directly to the plant when symptoms appear
Applying Micronutrients

- **Organic materials** – most animal manures will contain different amounts of micronutrients, as well as other organic fertilizers like seaweed or fish meal.
When is foliar a good idea?

• When the amount of nutrient needed is small
  – You need less foliar than soil applied
  – If you need a lot, it is better soil applied, may damage tissue
  – You may also have to make more applications

• When you need the nutrient later in the season
  – Soil applied may not reach the roots in time
What is a chelated micronutrient?

• Similar to how organic matter can hold micronutrients

• Protects the nutrient from soil chemical or biological reactions
  – E.g it won’t convert into an insoluble solid or be used by microbes

• May absorb through leaf tissue easier
What should I do about micronutrients?

• Keep your soil pH between 5.5 to 6.5 (up to 7 is OK)
  – Sandy better at 6.0 and clay textures at 6.5

• If only have a few soil samples, pay more to see the whole suite of soil nutrients

• If your acreage is a lot larger, know your soil types
  – Sandy and organic soils are more likely to have deficiencies

• Look for deficiencies in your crops and take soil/tissue tests
  – It may be too late this year, but you can alleviate it next year
Issues can be fixed

- This field was over-limed
  - pH 7
- Mn deficiency was evident
- Tillage before the next planting mixed the lime deeper
- Alleviated the issue
Manganese – Recognizing Deficiency
Questions?