Nutrients & Diagnosing Nutrient Needs

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Sources of nutrients available for plant uptake

- Nutrients in the soil solution are:
  - In ionic form
  - At low concentration
  - Highly buffered

- Contributors to soil solution:
  - Exchange sites on clay and organic matter
  - Organic matter decomposition
  - Weathering of soil minerals and rocks
  - Atmosphere & precipitation
  - Organic and inorganic additions
Movement of nutrients to roots

- Mass flow
- Diffusion
- Root interception
Mass flow – dissolved nutrients move to the root in soil water that is flowing towards the roots.
**Diffusion** – nutrients move from higher concentration in the bulk soil solution to lower concentration at the root;

- In the time it takes $\text{NO}_3^-$ to diffuse 1 cm, $\text{K}^+$ diffuses 0.2 cm, and $\text{H}_2\text{PO}_4^-$ diffuses 0.02 cm
Root interception – roots obtain nutrients by physically contacting nutrients in soil solution or on soil surfaces;
- roots contact ~1% of soil volume;
- mycorrhizal infection of root increase root-soil contact

\[ \text{Zn}^{2+}, \text{Mn}^{2+}, \text{H}_2\text{PO}_4^- \]
Principal ways in which ions move from soil to the roots of corn

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Amount of Nutrient Required for 150 bu/a of Corn (lb/a)</th>
<th>Percentage Supplied by Root Interception</th>
<th>Mass Flow</th>
<th>Diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>170</td>
<td>1</td>
<td>99</td>
<td>0</td>
</tr>
<tr>
<td>P</td>
<td>35</td>
<td>3</td>
<td>6</td>
<td>94</td>
</tr>
<tr>
<td>K</td>
<td>175</td>
<td>2</td>
<td>20</td>
<td>78</td>
</tr>
<tr>
<td>Ca</td>
<td>35</td>
<td>171</td>
<td>429</td>
<td>0</td>
</tr>
<tr>
<td>Mg</td>
<td>40</td>
<td>38</td>
<td>250</td>
<td>0</td>
</tr>
<tr>
<td>S</td>
<td>20</td>
<td>5</td>
<td>95</td>
<td>0</td>
</tr>
<tr>
<td>Cu</td>
<td>0.1</td>
<td>10</td>
<td>400</td>
<td>0</td>
</tr>
<tr>
<td>Zn</td>
<td>0.3</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>B</td>
<td>0.2</td>
<td>10</td>
<td>350</td>
<td>0</td>
</tr>
<tr>
<td>Fe</td>
<td>1.9</td>
<td>11</td>
<td>53</td>
<td>37</td>
</tr>
<tr>
<td>Mn</td>
<td>0.3</td>
<td>33</td>
<td>133</td>
<td>0</td>
</tr>
<tr>
<td>Mo</td>
<td>0.01</td>
<td>10</td>
<td>200</td>
<td>0</td>
</tr>
</tbody>
</table>

Barber, Soil Bionutrient Availability, (1984). Diffusion estimated be difference between total nutrient need and nutrient supply by root interception & mass flow.
Ion absorption by plants:

- **Passive uptake**
  - Simple diffusion – small nonpolar molecules \((O_2, CO_2)\)
  - Facilitated diffusion – small polar species \((H_2O, ions, amino acids)\)
  - Transporter proteins
    - Energy required is obtained from electrical/chemical gradient, not plant

- **Active uptake**
  - Larger, more charged molecules (sugars, phosphate/ions, DNA, proteins, etc.)
  - Selectively permeable membrane requires plant to expend energy to transport ions against a concentration gradient
Nutrient Availability

- Macronutrients
  - Structural: C, O, H
  - Primary: N, P, K
  - Secondary: Ca, Mg, S

- Micronutrients
  - B, Mn, Zn
  - Cu, Fe, Mo, Cl, Ni
## Macronutrients – Structural

<table>
<thead>
<tr>
<th>Element</th>
<th>Main Function</th>
<th>Primary Source</th>
<th>Approx. Concentration in Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>Part of all organic compounds</td>
<td>Carbon dioxide in air</td>
<td>45%</td>
</tr>
<tr>
<td>(C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Forms main structural components</td>
<td>Water</td>
<td>6%</td>
</tr>
<tr>
<td>(H)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>Forms main structural components</td>
<td>Water, air</td>
<td>43%</td>
</tr>
<tr>
<td>(O)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Macronutrients – Primary

<table>
<thead>
<tr>
<th>Element</th>
<th>Main Function</th>
<th>Primary Source</th>
<th>Approx. Conc. in Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N)</td>
<td>Component of proteins, chlorophyll, nucleic acids</td>
<td>Soil OM; fixation of atmospheric N (legumes)</td>
<td>1-6%</td>
</tr>
<tr>
<td>Phosphorus (P)</td>
<td>Energy transfer; metabolism, nucleic acids, nucleoproteins</td>
<td>Soil organic matter soil minerals</td>
<td>0.05-1%</td>
</tr>
<tr>
<td>Potassium (K)</td>
<td>Protein synthesis; translocation of carbohydrates; enzyme activation</td>
<td>Soil minerals</td>
<td>0.3-6%</td>
</tr>
</tbody>
</table>
Nitrogen

- $\text{NO}_3^-$ and $\text{NH}_4^+$ taken up by roots

- $\text{NO}_3^-$ mobile in the soil
  - Leaches readily

- $\text{NH}_4^+$ held to soil cation exchange

- Most N is in organic forms
  - Undergoes many transformations
Phosphorus

- Is taken up by roots as $\text{H}_2\text{PO}_4^-$ or $\text{HPO}_4^{2-}$

- Generally not mobile in soil
  - Except under conditions of high soil test levels

- Plants get P by root interception

- Most available at $5.5 < \text{pH} < 7.2$

- Cycles between organic and inorganic forms
Potassium

- Moderately mobile in the soil
- Plants obtain K mainly by diffusion
- Is held on the cation exchange
  - Greater CEC results in greater availability

- Natively K comes from soil minerals
  - Slow process of mineral weathering
  - Added K can be fixed in these minerals
POTASSIUM DEFICIENCY

CHLOROSIS & MARGINAL NECROSIS
## Macronutrients – Secondary

<table>
<thead>
<tr>
<th>Element</th>
<th>Main Function</th>
<th>Primary Source</th>
<th>Approx. Conc. in Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (Ca)</td>
<td>Structural component of cell walls; cell elongation; affects cell permeability</td>
<td>Soil minerals, limestone</td>
<td>0.1-3%</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>Component of chlorophyll; enzyme activator; cell division</td>
<td>Soil minerals, dolomitic limestone</td>
<td>0.05-1%</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>Constituent of proteins; involved in respiration and nodule formation</td>
<td>Soil organic matter, rainwater</td>
<td>0.05-1.5%</td>
</tr>
</tbody>
</table>
Calcium

- Is mobile in the soil
  - Moves to root by mass flow
  - Can be leached – particularly sandy soils
  - Deficiency sometimes seen in dry soils when there isn’t enough water to transport Ca

- Is held on the cation exchange
- Low pH soils likely to be low in Ca
Magnesium

- Moves to root via mass flow & diffusion
  - Leaches somewhat more than Ca
- Held on the cation exchange
- Deficiency occurs in low pH soils
Sulfur

- Is mobile in soil; \( \text{SO}_4^{2-} \)
- Mass flow and diffusion supply roots

- Availability dependant on amount of OM
  - Undergoes transformations similar to N

- More deficiencies are occurring because
  - Less atmospheric deposition
  - N-P-K fertilizer are purer contain less S
## Micronutrients

<table>
<thead>
<tr>
<th>Element</th>
<th>Main Function</th>
<th>Primary Source</th>
<th>Approx. Conc. in Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe)</td>
<td>Chlorophyll synthesis; oxidation-reduction reactions; enzyme activator</td>
<td>Soil minerals</td>
<td>10-1000 ppm</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>Oxidation-reduction reactions; nitrate reduction; enzyme activator</td>
<td>Soil minerals</td>
<td>5-500 ppm</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>Enzyme activator; nitrate reduction; respiration</td>
<td>Soil minerals; soil organic matter</td>
<td>2-50 ppm</td>
</tr>
<tr>
<td>Zinc (Z)</td>
<td>Enzyme activator; regulates pH of cell sap</td>
<td>Soil minerals; soil organic matter</td>
<td>5-100 ppm</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>Cell maturation and differentiation; translocation of carbohydrates</td>
<td>Soil organic matter; tourmaline</td>
<td>2-75 ppm</td>
</tr>
</tbody>
</table>
Iron

- Deficiency not observed on field or vegetable crops in WI

- Turfgrass, pin oak, some ornamentals
  - Deficiency on soils with pH > 7.5
Manganese

- Immobile in the soil
- Exists in mineral & organic forms
  - Held by clays and OM

Availability influenced by:
- pH: most available $5.0 < \text{pH} < 6.5$
- OM: high OM decreases availability
- Acidifying fertilizers increase Mn$^{2+}$ uptake
Copper

- Usually only seen on very acid soils
  - Particularly mucks

- Not easily leached
- Not easily fixed in unavailable forms
- Thus, repeated application not necessary

- Toxicities reported at high levels of use
Zinc

- Immobile in the soil
- Is held on clay, OM, & carbonates
- pH induced deficiencies 6 < pH < 8

Deficiency more likely on:
  - Severely eroded soils
  - Sands/loamy sands
  - Muck soils
Boron

- Highly mobile in soil
  - Can leach; sandy soils with low OM

- Bound to clay and OM

- Availability decreases at pH > 6.5

- Boron can injure sensitive crops
  - Dry bean, soybean, corn, & small grains
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<thead>
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<th>Main Function</th>
<th>Primary Source</th>
<th>Approx. Conc. in Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molybdenum (Mo)</td>
<td>Nitrate reduction; fixation of atmospheric nitrogen by legumes</td>
<td>Soil organic matter; soil minerals</td>
<td>0.01-10 ppm</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>Photochemical reactions in photosynthesis</td>
<td>Rainwater</td>
<td>0.05-3%</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>Enzyme activation (urease), N metabolism</td>
<td>Soil Minerals</td>
<td>0.01-10 ppm</td>
</tr>
</tbody>
</table>
Molybdenum

- Only micronutrient where availability increases as soil pH increases
- Liming soils to optimal pH levels usually eliminates deficiencies
Chlorine

- Deficiency never observed in WI
- Crop only needs small amount
- Often applied in fertilizer salts (KCl), manure, rainwater
Nickel

- Most recent nutrient considered to be essential (1987)
- Needed in very small amount
- Deficiency not observed in WI
## Beneficial/Enhancing Nutrients

<table>
<thead>
<tr>
<th>Element</th>
<th>Main Function</th>
<th>Primary Source</th>
<th>Approx. Conc. in Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium (Na)</td>
<td>K substitution, flavor enhancer, ionic balance</td>
<td>Soil minerals</td>
<td>0.3-3%</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>Strengthen cell walls, reduces micronutrient toxicity</td>
<td>Soil minerals</td>
<td>0.5-15%</td>
</tr>
<tr>
<td>Cobalt (Co)</td>
<td>N2 fixation, enzyme activity</td>
<td>Soil minerals</td>
<td>0.3-4 ppm</td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>Sulfur substitution “white muscle disease” reproductive disorder</td>
<td>Soil minerals</td>
<td>1-1000 ppm</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>Stimulate root growth</td>
<td>Soil minerals</td>
<td>20-2000 ppm</td>
</tr>
</tbody>
</table>
Plant Analysis
Plant Analysis Uses

- Identify deficiency symptoms
  - Determine nutrient shortages before they appear as symptoms

- Aid in determining nutrient supplying capacity of the soil
  - Need soil test and field history

- Aid in determining effect of nutrient addition on the nutrient supply in the plant

- Study the relationship between nutrient status of plant and crop performance
Types of Plant Analysis

- **Cell sap tests**
  - Usually in-field, quick tests, semiquantitative

- **Total analysis**
  - Lab tests on whole plant or specific part
    - Sampled part may be dependent on growth stage
  - Provides an indicator of plant nutritional status
  - Assumes nutritional status is related to soil nutrient availability
Tissue Sampling

- What to sample
- When to sample
- Sample handling
  - Refrigerated (kept cold)
  - Removal of contaminants (soil, dust, fertilizer)
- Interpretation
## What & When to Sample

### Table 12-13. Proper plant sampling for diagnostic plant analysis

<table>
<thead>
<tr>
<th>Crop</th>
<th>Stage of growth</th>
<th>Plant part</th>
<th>Number of plants to sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa, birdsfoot trefoil, clover</td>
<td>Prior to flowering</td>
<td>Top 6 inches</td>
<td>35</td>
</tr>
<tr>
<td>Asparagus, onion</td>
<td>Boot</td>
<td>Top 6 inches</td>
<td>20</td>
</tr>
<tr>
<td>Bean, pea</td>
<td>Prior to or at initial flowering</td>
<td>Newest fully developed leaf</td>
<td>25</td>
</tr>
<tr>
<td>Beets, broccoli, brussels sprouts, cabbage, carrot, cauliflower, celery, lettuce, radish, spinach, tobacco</td>
<td>Midseason</td>
<td>Upper mature leaves</td>
<td>20</td>
</tr>
<tr>
<td>Corn</td>
<td>a) Seedling to 20 inches high</td>
<td>Whole plant above ground</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>b) 20 inches high to flag leaf</td>
<td>Newest fully developed leaf</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>c) Tasseling to silking</td>
<td>Earleaf or opposite &amp; below</td>
<td>15</td>
</tr>
<tr>
<td>Cucumber, melon, pumpkin, squash</td>
<td>Prior to or at initial flowering</td>
<td>Newest fully developed leaf</td>
<td>25</td>
</tr>
<tr>
<td>Forage (grasses, grains)</td>
<td>Prior to heading</td>
<td>Newest fully developed leaf</td>
<td>50</td>
</tr>
<tr>
<td>Mint</td>
<td>Boot</td>
<td>Whole plant</td>
<td>20</td>
</tr>
<tr>
<td>Pepper, potato, tomato</td>
<td>Prior to or at initial flowering</td>
<td>Newest petiole and leaflet</td>
<td>40</td>
</tr>
<tr>
<td>Sorghum (grain, sudan)</td>
<td>Prior to heading</td>
<td>Second fully developed leaf</td>
<td>20</td>
</tr>
<tr>
<td>Apple, cherry, pear, plum</td>
<td>Current season’s shoots taken July 1–15</td>
<td>Fully developed leaf at midpoint of new shoots</td>
<td>4 leaves from each of 10 trees</td>
</tr>
<tr>
<td>Grape</td>
<td>Bearing primary shoots</td>
<td>Petioles from newest leaves</td>
<td>5 petioles from each of 10 vines</td>
</tr>
<tr>
<td>Strawberry</td>
<td>Current season’s shoots</td>
<td>New petioles and leaves</td>
<td>5 parts from each of 10 plants</td>
</tr>
</tbody>
</table>
Relationship between nutrient concentration in leaves over the growing season

Redrawn from Havlin et al., 2005
Growth (% of maximum)

Critical Nutrient Range (no symptoms)

Critical Concentration

Concentration of Nutrient in Tissue (dry basis)

Luxury Consumption

Toxicity

Visual Symptoms

10% Reduction in Growth

Redrawn from Havlin et al., 1999
Tissue Test Interpretation

- Critical nutrient concentration ranges (sufficiency ranges)
  - Using Plant Analysis as a Diagnostic Tool
    see New Horizons in Soil Science 2000
    http://www.soils.wisc.edu/extension/publications/horizons/index.htm

- **DRIS** (Diagnostic & Recommendation Integrated System)

- **PASS** (Plant Analysis with Standardized Scores)
Correction of deficiencies identified with tissues tests may not be feasible because:

- Deficiency may have already caused yield loss
- Crop may not respond at the growth stage tested
- Crop may be too large for nutrient application
- Weather may be unfavorable for fertilization and/or for crop to benefit

From Havlin et al., 2005
Using plant analysis to help diagnose a field problem

- **Not a clear cut tool**
- Need to collect all the evidence:
  - Nutrient deficiency symptoms
  - Root growth patterns
  - Weather
  - Current field conditions
  - Field history
  - Tissue analysis
  - Soil analysis
Soil Testing & Nutrient Recommendations
Objectives of Soil Tests

1. Provide an index of nutrient availability (or supply) in a given soil
   - A soil test measures a portion of a nutrient from a “pool” that is used by plants
   - Calibration

- Sorbed P
  - Clays, Fe, Al oxides

- Secondary P Minerals
  - Ca, Fe, Al phosphates

- Partial P Cycle

- Soil Solution P

- Organic P

- Fertilizer
2. Predict the probability of obtaining a profitable response to lime and fertilizer
   - On low testing soils, a response to applied nutrients may not always be obtained because of other limiting factors (moisture, pH, other nutrients)
   - **BUT** the probability of a response to nutrient additions on low testing soils is greater than high testing soils
   - Correlation
Objectives of Soil Tests

3. Provide a basis for recommendations on the amount of lime and fertilizer to apply
   - Relationships obtained through laboratory, greenhouse, and field studies
Overriding Goal of Soil Testing

- To obtain a value that will help to predict the amount of nutrients (fertilizer) needed to supplement the nutrient supplying capacity of the soil such that maximum economic yield is achieved
  - Now, and more so in the future, we will need to balance environmental degradation with economics
Nutrient Recommendation Philosophies

- Build and Maintain
- Sufficiency Level
- Cation Ratio/Balance

- For immobile nutrients
  - Primarily P & K, not N
**Goal:** Apply nutrients such that soil tests are built up to a certain level and then maintained within a range.

- **Feed the soil theory**
- **Provides a margin of safety to compensate for differential crop response**

<table>
<thead>
<tr>
<th>Nutrient Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Buildup Range</strong></td>
</tr>
<tr>
<td><strong>Critical Level</strong></td>
</tr>
<tr>
<td><strong>Maintenance Range</strong></td>
</tr>
<tr>
<td><strong>Drawdown Range</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Test Level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Buildup</strong></td>
</tr>
<tr>
<td><strong>Critical Level</strong></td>
</tr>
<tr>
<td><strong>Maintenance Limit</strong></td>
</tr>
<tr>
<td><strong>Drawdown Range</strong></td>
</tr>
</tbody>
</table>
**Sufficiency Level**

- Soil test levels established & identified by likelihood of a crop response
  - Low soil test = crop response assured
  - Medium soil test = crop response possible
  - High soil test = crop response marginal
  - Very high soil test = crop response unlikely

- Nutrient recommended only for low through high soil tests

- Fertilize the crop theory
Soil Test Interpretation Categories

<table>
<thead>
<tr>
<th>Soil Test Level</th>
<th>Relative Supply of Nutrients From Soil and Fertilizer</th>
<th>Probability of Yield Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>Soil waynutated =&gt; Fertilizer</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>High</td>
<td>Soil waynutated =&gt; Fertilizer*</td>
<td>5-30%</td>
</tr>
<tr>
<td>Optimum</td>
<td>Soil =&gt; Fertilizer</td>
<td>30-60%</td>
</tr>
<tr>
<td>Low</td>
<td>Soil =&gt; Fertilizer</td>
<td>60-90%</td>
</tr>
<tr>
<td>Very Low</td>
<td>Soil =&gt; Fertilizer</td>
<td>&gt;90%</td>
</tr>
</tbody>
</table>

Nutrients available from soil

Nutrients required

Adapted from Havlin et al., 1999 using WI interpretations

* Fertilizers used at high soil test levels are for starter or maintenance purposes
## Relationship Between Soil Test and Fertilizer Recommendations in WI

<table>
<thead>
<tr>
<th>Soil Test Category</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low, Low</td>
<td>Crop removal +</td>
</tr>
<tr>
<td>Optimum</td>
<td>Crop removal</td>
</tr>
<tr>
<td>High, Very High</td>
<td>½ or ¼ Crop removal</td>
</tr>
<tr>
<td>Excessively High</td>
<td>None</td>
</tr>
</tbody>
</table>
Basic Cation Saturation Ratios (BCSR)

- Concept that there is an ideal ratio or range of ratios that maximizes crop production
  - Eg. 65-85% Ca, 6-12% Mg, 2-5% K

- Research in WI does not support this theory

- Relying on cation ratios has several drawbacks:
  - OK ratio, but nutrient supply not sufficient
  - Not OK ratio, but nutrient supply sufficient
  - No economic analysis goes into recommendations that use the cation ratio approach
Quotes from BCSR Researchers

“Basic cation ratios per se seem unimportant to the well-being of the crop. Indeed, it appears that instead we should concentrate on sufficiency levels of each basic cation.”

E.O. McLean, 1982

“Emphasis should be placed on providing sufficient, but non-excessive levels of each basic cation rather than attempting to adjust to a favorable BCSR which evidently does not exist.”

McLean et al., 1983
UW Department of Soil Science

http://www.soils.wisc.edu/extension