DAFFODILS ARE WHAT THEY EAT: NUTRITIONAL ASPECTS OF SOILS

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University of Wisconsin - Madison
Basic concepts of soil fertility

How plants absorb nutrients
  • movement to the root surface
  • absorption into plant

Determining nutrient need

Essential plant nutrients
  • categories
  • effect of soil characteristics

Liming
Sources of nutrients to plants

Soil solution
- ionic form
- low concentration
- highly buffered

Contributors to the soil solution
- exchange sites on clay and organic matter
- organic matter and microorganisms
- soil rocks and minerals
- atmosphere and precipitation
- fertilizer and other additions
Movement of ions from soils to roots

- Root interception
- Mass flow
- Diffusion
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
Ion absorption by plants:

Passive uptake
- diffusion
- ion exchange

Active ion uptake
- ion carriers
- selective / competitive
Cation Exchange Capacity (CEC)

- Cations – positively charged ions eg. K^+
- CEC – soil property
  - Ability of soil to hold cations
    - Nutrients or other polar molecules
- Units are meq/100 g or cmol_c/kg
  - Number is the same regardless of units

\[
\text{Al}^{3+} > \text{H}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ = \text{NH}_4^+ > \text{Na}^+
\]
Importance of CEC

- Nutrient retention
- Nutrient availability
- Act as buffer
- Control levels of waste disposal
- Control levels of herbicide
Soil properties that affect CEC

- Amount of clay
- Amount of organic matter
- pH
- Type of clay
- Estimated by summing exch. $\text{Ca} + \text{Mg} + \text{K}$

Est. CEC = \( \frac{\text{ppm Ca}}{200} \times \frac{\text{ppm Mg}}{122} \times \frac{\text{ppm K}}{391} \)
# CEC range for various soil textures

<table>
<thead>
<tr>
<th>Texture</th>
<th>CEC (meq/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sands (light colored)</td>
<td>3 – 5</td>
</tr>
<tr>
<td>Sands (dark colored)</td>
<td>10 – 20</td>
</tr>
<tr>
<td>Loams</td>
<td>10 – 15</td>
</tr>
<tr>
<td>Silt loams</td>
<td>15 – 25</td>
</tr>
<tr>
<td>Clays and clay loams</td>
<td>20 – 50</td>
</tr>
<tr>
<td>Organic soils</td>
<td>50 – 100</td>
</tr>
</tbody>
</table>

From Havlin et al., 2005
Determining nutrient need

• Visual symptoms
• Soil testing
• Plant analysis
Soil testing is the only preplant method of knowing nutrient need!

**WHAT SOIL TESTING TELLS US**

- Crop N need
- Plant available P and K
- Crop P and K need
- Soil organic matter
- Soil pH and lime requirement
- Other tests if requested
Soil sampling for lawns and gardens

- Sample depth
  - 4” for turf
  - 6” for gardens
  - depth of bed
- How
  - 8-10 cores per sample
  - well mixed
- When
  - fall or early spring
  - every 2-3 years
Recommendations

• Index of nutrient availability
• Probability of response
• Basis for recommendations

UW Soil and Plant Analysis Lab
8452 Mineral Point Rd, Verona 53593
(West Madison Ag. Research Station)
Goals of nutrient management

• Maximize economic return
• Avoid environmental risks due to above-optimum use
• Rate, source, method, timing
Common soil test results

• Many soils have excessive P and K levels
  – Un-managed applications
  – Not detrimental
  – Adding more not beneficial

• pH may need modification
  – Raise with lime
  – Lower with elemental sulfur

• Over-application of N
  – Delays maturity
  – Excessive vegetative growth
  – Possible leaching of nitrate
Plant analysis

- “Snapshot” of nutrient status of plant sampled
- Multi-nutrient
- Useful for nutrients for which soil tests do not exist
- Identify deficiencies, toxicities, imbalances
- Routinely or when problems occur
Limitations of plant analysis

- Interpretation difficulties
  - plant parts
  - stage of growth
  - not well calibrated for horticultural plants
- Inter-relationship with other factors
- Progressive deficiencies
- Sample contamination/deterioration
Plant analysis method

Monitoring

* 2 samples minimum
* “best” plant part and stage of growth
* avoid unusual plants/areas

Problem solving

* sample normal and abnormal areas
* early as possible
* correct plant part for stage of growth

Include soil sample and management history
How to remember the 17 essential elements

C HOPKINS CaFe is Mighty
Nice, But Many More
Prefer Clara’s Zany Cup

- Required for the plant to complete life cycle
- Directly involved in metabolism
- Can not be substituted by another nutrient
- Essential for a wide range of plants
## Essential nutrients

<table>
<thead>
<tr>
<th>Element</th>
<th>Main Function</th>
<th>Primary Sources</th>
<th>Approx. conc. In plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (C)</td>
<td>Part of all organic compounds</td>
<td>Carbon dioxide in air</td>
<td>45%</td>
</tr>
<tr>
<td>Hydrogen (H)</td>
<td>Forms main structural components</td>
<td>Water</td>
<td>6%</td>
</tr>
<tr>
<td>Oxygen (O)</td>
<td>Forms main structural components</td>
<td>Water, air</td>
<td>43%</td>
</tr>
</tbody>
</table>
# Essential nutrients – primary nutrients

<table>
<thead>
<tr>
<th>Element</th>
<th>Main Function</th>
<th>Primary Sources</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 organic matter; fixation of atmospheric nitrogen (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 (N)

- Atmosphere contains 78% nitrogen gas ($N_2$)
- Plants cannot use this N directly
- Nitrogen from air must be converted for plant use
  - Biological fixation (Rhizobia and legumes)
  - Chemical fixation (fertilizers)
# C:N of organic materials

<table>
<thead>
<tr>
<th>Material</th>
<th>C : N Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil microorganisms</td>
<td>8</td>
</tr>
<tr>
<td>Soil organic matter</td>
<td>10</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>12</td>
</tr>
<tr>
<td>Rotted manure</td>
<td>20</td>
</tr>
<tr>
<td>Corn residue</td>
<td>60</td>
</tr>
<tr>
<td>Grain straw</td>
<td>80</td>
</tr>
<tr>
<td>Sawdust</td>
<td>300</td>
</tr>
<tr>
<td>Sugar</td>
<td>?</td>
</tr>
<tr>
<td>Expected N Effect</td>
<td>C : N range</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Mineralize (release) N</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>Depends on weather composition, mixing</td>
<td>20 - 30</td>
</tr>
<tr>
<td>Immobilize (tie up) N</td>
<td>&gt; 30</td>
</tr>
</tbody>
</table>
Soil Solution P
\[ \text{HPO}_4^{2-} \text{ & H}_2\text{PO}_4^- \]

Sorbed P
Clays
Al, Fe Oxides

Secondary P Minerals
Ca, Fe, Al phosphates

Primary P Minerals
Apatites

Plant Uptake

Erosion, Runoff
Sediment & Soluble P

Municipal & Industrial By-Products
Agricultural Wastes
Plant Residues
Fertilizer

Soil Biomass (living)
Soil Organic Matter
Soluble Organic P

Immobilization
Mineralization

Leaching

(Redrawn from Pierzynski et al., 1994)
Soil P buffering capacity

- Soil test P changes slowly with additions or removals

- 18 lb $P_2O_5$/acre needed to change soil test P by 1 ppm for medium- and fine-textured soils
  - 12 lb $P_2O_5$/acre/ppm for coarse-textured soils
P availability affected by pH

## Interpreting soil test P results

<table>
<thead>
<tr>
<th>Crop</th>
<th>Medium &amp; fine soils</th>
<th>Course textured soils</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Optimum</td>
<td>No response</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>16 – 23</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Corn</td>
<td>14 – 18</td>
<td>&gt; 28</td>
</tr>
<tr>
<td>Soybean</td>
<td>6 – 10</td>
<td>&gt; 20</td>
</tr>
</tbody>
</table>

Soil Test P (ppm)
Factors affecting P fertilizer management

• Placement & Mixing
  – Band v. broadcast

• Source
  – Analysis
  – Liquid v. dry
  – Ortho v. poly

• Interaction with $\text{NH}_4^+$-N
  – Stimulates P adsorption by root

• Soil test P level
Potassium cycle

Havlin et al., 2001
## Interpreting soil test K results

<table>
<thead>
<tr>
<th>Crop</th>
<th>Medium &amp; fine soils</th>
<th>Course textured soils†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Optimum</td>
<td>No response</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>91 – 120</td>
<td>&gt; 170</td>
</tr>
<tr>
<td>Corn</td>
<td>81 – 100</td>
<td>&gt; 140</td>
</tr>
<tr>
<td>Soybean</td>
<td>81 – 100</td>
<td>&gt; 140</td>
</tr>
</tbody>
</table>

† Not irrigated
Environmental factors affecting K availability to a plant

• Soil moisture
  – Low soil moisture results in more tortuous path for K diffusion – takes longer to get to root
  – Increasing K levels or soil moisture will increase K diffusion
  – Increase soil moisture from 10 to 28 % can increase total K transport by up to 175 %

• Soil Aeration
  – High moisture results in restricted root growth, low $O_2$ and slowed K absorption by the root

78 % of K supplied to root via diffusion
Environmental factors affecting K availability to a plant

• Soil temperature
  – Low temperature restricts plant growth and rate of K uptake
  – Providing high K levels will increase K uptake at low temperatures
    • Reason for positive response to banded starter

• Soil pH
  – At low pH, K has more competition for CEC sites
  – As soils are limed, greater amount of K can be held on CEC and K leaching reduced.
Environmental factors affecting K availability to a plant

• Leaching
  – K leaching can occur on course textured or muck soils particularly if irrigated
  – Large fall K applications to sandy or muck soils discouraged
# Essential nutrients – secondary nutrients

<table>
<thead>
<tr>
<th>Secondary Essential nutrients</th>
<th>Element</th>
<th>Main Function</th>
<th>Primary Sources</th>
<th>Approx. conc. In plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<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></td>
<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></td>
<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 & magnesium cycle

Figure 7-12  Ca and Mg cycling in soil.

From Havlin et al., 2005
Factors affecting Ca availability

- **Total Ca supply & % Ca saturation of CEC**
  - Low CEC soil with 1000 ppm Ca supply more Ca to plants than high CEC soil with 2000 ppm Ca

- **Soil pH**
  - Low soil pH impedes Ca uptake

- **Type of soil clay**
  - 2:1 clays require > Ca saturation of CEC compared to 1:1 clays to supply adequate Ca

- **Ratio of solution Ca\(^{2+}\) to other cations**
  - Uptake depressed by \(\text{NH}_4^+, \text{K}^+, \text{Mg}^+, \text{Mn}^{2+}, \text{Al}^{2+}\)
  - Absorption increased by \(\text{NO}_3^-\)
Magnesium availability

- Total Mg supply
- CEC
- pH

<table>
<thead>
<tr>
<th>Texture</th>
<th>Very Low</th>
<th>Low</th>
<th>Opt</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>coarse</td>
<td>0-25</td>
<td>26-50</td>
<td>51-250</td>
<td>&gt;251</td>
</tr>
<tr>
<td>medium &amp; fine</td>
<td>0-50</td>
<td>51-100</td>
<td>101-500</td>
<td>&gt;500</td>
</tr>
</tbody>
</table>
Factors affecting Mg availability

- Excess K applications on sandy soil
  - Cause Mg leaching
  - K interferes with Mg uptake

- Continuous use of high Ca lime increases Ca:Mg ratio
  - May induce Mg deficiency in certain crops

- NH$_4^+$ induced Mg deficiency
  - High rates of NH$_4^+$ on soils with low exchangeable Mg
Sulfur (S)

- Building block for plant protein
- High need for sulfur in forage legumes
  - alfalfa, etc.
- Availability dependant on amount of soil OM
  - Undergoes transformations similar to N
  - Shortages interfere with N uptake
- More deficiencies are occurring because:
  - Less atmospheric deposition
  - N-P-K fertilizer are purer contain less sulfur
Conditions that could result in S deficiencies

- Low organic matter soils (sands)
- No recent manure applications
- Less sulfur in rainfall
  - i.e. cleaner air
  - Traditionally more of a concern in N & W Wis.
- Low subsoil sulfur
Average, annual sulfur deposition from precipitation at selected Wisconsin locations

<table>
<thead>
<tr>
<th>Location</th>
<th>1969-71</th>
<th>1985-87</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arlington</td>
<td>36</td>
<td>21</td>
</tr>
<tr>
<td>Lancaster</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>Marshfield</td>
<td>46</td>
<td>20</td>
</tr>
<tr>
<td>Spooner</td>
<td>12</td>
<td>9</td>
</tr>
</tbody>
</table>
# Essential nutrients - micronutrients

<table>
<thead>
<tr>
<th>Element</th>
<th>Main Function</th>
<th>Primary Sources</th>
<th>Approx. conc. In plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>Chlorophyll synthesis; oxidation-reduction reactions; enzyme activator</td>
<td>Soil minerals</td>
<td>10-1000 ppm</td>
</tr>
<tr>
<td>(Fe)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>Oxidation-reduction reactions; nitrate reduction; enzyme activator</td>
<td>Soil minerals</td>
<td>5-500 ppm</td>
</tr>
<tr>
<td>(Mn)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>Enzyme activator; nitrate reduction; respiration</td>
<td>Soil minerals; soil organic matter</td>
<td>2-50 ppm</td>
</tr>
<tr>
<td>(Cu)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc</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>(Zn)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td>Cell maturation and differentiation; translocation of carbohydrates</td>
<td>Soil organic matter; tourmaline</td>
<td>2-75 ppm</td>
</tr>
<tr>
<td>(B)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Essential nutrients - micronutrients

<table>
<thead>
<tr>
<th>Element</th>
<th>Main Function</th>
<th>Primary Sources</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>
## Relative Micronutrient Requirements of Crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Micronutrient</th>
<th>Micronutrient</th>
<th>Micronutrient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boron</td>
<td>Manganese</td>
<td>Zinc</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Corn</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Soybean</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Cabbage</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Beets</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Potato</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Micronutrient fertilizers

• Apply only when:
  - Soil test is low
  - Deficiency symptoms on plant
  - Plant analysis indicates deficiency
  - High crop requirement
Plants let us know when they’re sick

- Specific appearance of symptom and plant position
- More likely on some soil types
- Plants have different sensitivities
- Symptoms not always nutrient related
CHLOROSIS & MARGINAL NECROSIS
What is soil pH?

- A measure of soil acidity
- Soil acidity affects many chemical and biological reactions
- Lime neutralizes soil acidity
Characteristics of soil acidity

• pH buffering
  – Ability of the soil to resist pH change
  – Increases with increasing CEC (texture)
    • Clay content
    • Organic matter content

• Reserve vs. active acidity
How a soil becomes acid

- Use of acid-forming fertilizers
- Removal of basic cations
  - $\text{Ca}^{2+}$, $\text{Mg}^{2+}$, $\text{K}^+$
  - Older soils tend to have more basic cations leached and have lower pH
- Respiration by plant roots
Beneficial effects of liming

- Crop yield improvement
- Nutrient availability effects
- Improved microbial activity
- Improved legume fixation
- Ca and Mg addition
Relationship between pH and nutrient availability
Choosing liming materials

- In Wisconsin, lime quality is listed by neutralizing index
  - NI = Fineness factor x Purity factor
  - Lime with CCE of 90% and fineness of 67
    - NI = 67 x 90% = 60.3

- Lime requirement (LR) in Wisconsin is given for NI of 60-69
  - If liming material has a NI different than above then,
    \[
    \text{LR (T/a) of material} = \frac{T/a \text{ of 60-69 LR}}{\text{NI of material}} \times \frac{65}{65}
    \]
Liming material fineness

Mesh size:
- > 8
- 8-20
- 20-60
- < 60
Effect of particle size on soil pH over 3 years

Figure 3-10 from Havlin et al., 2005
# The purity factor (CaCO₃) equivalent

Table 6-5. Liming materials and their calcium carbonate (CaCO₃) equivalent

<table>
<thead>
<tr>
<th>Liming material</th>
<th>Neutralizing agent</th>
<th>CaCO₃ equivalent of pure material (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dolomitic limestone</td>
<td>CaCO₃•MgCO₃</td>
<td>110–118</td>
</tr>
<tr>
<td>Papermill lime sludge</td>
<td>Mainly CaCO₃</td>
<td>*</td>
</tr>
<tr>
<td>Marl</td>
<td>Mainly CaCO₃</td>
<td>variable</td>
</tr>
<tr>
<td>Calcitic limestone</td>
<td>CaCO₃</td>
<td>100</td>
</tr>
<tr>
<td>Water treatment lime waste</td>
<td>CaCO₃</td>
<td>variable</td>
</tr>
<tr>
<td>Wood ash</td>
<td>K₂CO₃, CaCO₃, MgCO₃</td>
<td>20–90</td>
</tr>
<tr>
<td>Fly ash</td>
<td>CaO, Ca(OH)₂, CaCO₃</td>
<td>variable</td>
</tr>
<tr>
<td>Hydrated lime</td>
<td>Ca(OH)₂</td>
<td>135</td>
</tr>
<tr>
<td>Air-slaked lime</td>
<td>Ca(OH)₂ + CaCO₃</td>
<td>100–135</td>
</tr>
</tbody>
</table>

* According to the Wisconsin Lime Law, one cubic yard of papermill lime sludge is equivalent to one ton of aglime having a neutralizing index of 60–69.
UW Department of Soil Science

Extension

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University of Wisconsin-Madison