Soil fertility & fertilizers

by
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Soil Nutrients

• Of all the elements plants need, 3 are needed in much larger quantities than all others combined.
  • Carbon (C)
  • Hydrogen (H)
  • Oxygen (O)
• Plants obtain C, H, and O from soil water and atmospheric carbon dioxide and assimilate them via photosynthesis:

\[
6\text{CO}_2 + 6\text{H}_2\text{O} + \text{sunlight} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]

Soil Nutrients

• Soil supplies at least 13 additional plant nutrients that are essential to plant growth.
• Without adequate amounts of any one of these 13 essential nutrients, a plant will not be able to survive and reproduce.
• These 13 essential plant nutrients are divided into two groups based upon the amount needed by plants:
  • Macronutrients
  • Micronutrients

Macronutrients

• Macronutrients are those needed by plants in relatively large amounts.
• Primary Macronutrients
  • Nitrogen (N)
  • Phosphorus (P)
  • Potassium (K)
• Secondary Macronutrients
  • Sulfur (S)
  • Calcium (Ca)
  • Magnesium (Mg)

Micronutrients

• Micronutrients are those needed by plants in relatively small amounts.
  • Chlorine (Cl)
  • Iron (Fe)
  • Boron (B)
  • Manganese (Mn)
  • Zinc (Zn)
  • Copper (Cu)
  • Molybdenum (Mo)

Micronutrients

• Other elements are sometimes identified as micronutrients, but they are not essential.
  • Bromine (Br)
  • Cobalt (Co)
  • Fluorine (F)
  • Iodine (I)
  • Nickel (Ni)
  • Rubidium (Rb)
  • Selenium (Se)
  • Silicon (Si)
  • Sodium (Na)
  • Strontium (Sr)
  • Tungsten (W)
  • Vanadium (V)
• Not all of these are used by every type of plant.
• Some of these substitute for other, essential elements.
**Average concentrations of mineral nutrients in plant shoot dry matter that are sufficient for adequate growth.**

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>% dry weight</th>
<th>relative number of atoms</th>
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<tbody>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>1.5</td>
<td>1000000</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>1.0</td>
<td>250000</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca</td>
<td>0.5</td>
<td>125000</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>0.2</td>
<td>80000</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
<td>0.2</td>
<td>60000</td>
</tr>
<tr>
<td>Sulfur</td>
<td>S</td>
<td>0.1</td>
<td>30000</td>
</tr>
<tr>
<td>Uranium</td>
<td>U</td>
<td>0.01</td>
<td>3000</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>0.01</td>
<td>2000</td>
</tr>
<tr>
<td>Boron</td>
<td>B</td>
<td>0.002</td>
<td>2000</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn</td>
<td>0.005</td>
<td>1000</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
<td>0.002</td>
<td>300</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>0.0006</td>
<td>100</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Mo</td>
<td>0.00001</td>
<td>1</td>
</tr>
</tbody>
</table>

Total: 3.52961


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**Nutrient Mobility in Soil**

- **Mobile**
  - NO₃⁻, SO₄²⁻, B(OH)₃, Cl⁻
  - “feed the plant”
- **Somewhat Immobile**
  - NH₄⁺, K⁺, Ca²⁺, Mg²⁺
- **Immobile**
  - P, Fe, Mn, Zn, Cu, Mo
  - “feed the soil”

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**Nutrient Mobility in Plants**

- **Mobile**
  - N, P, K, Mg, Cl
  - (S)
- **Somewhat Immobile**
  - Fe, Mn, Zn, Cu, Mo
- **Immobile**
  - Ca, B
- Deficiency symptoms!

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**Glucose (C₆H₁₂O₆)**


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**PERIODIC TABLE OF THE ELEMENTS**

Mg-deficient potato (right)

Mg-deficient grape

N-deficient potato (right)

General structure for a peptide or a protein
Adenosine TriPhosphate (ATP)

Boron

- Boron is a micronutrient of particular concern due to its toxicity to both plants and animals in high concentrations.
- Borax is about 11% Boron and can be used at a rate of 1 Tbsp per 100 ft² when B fertilization is required (mix with water!)
- Never band B! Always broadcast, and never use more than recommended.
B-deficient pears


B-deficient apple


Apple anthracnose


B-deficient stone fruit


B-deficient grape


B toxicity in grape

Nutrient Availability

- ~98% of the nutrients used by plants are taken up from the soil solution.
- pH has a dramatic effect on nutrient availability!
**Raising pH**

- Use liming materials to raise the pH of acidic soils.
  - Lime: CaCO₃
  - Dolomitic: CaMg(CO₃)₂
- Available in powdered or pelletized forms.
- Ca/Mg ratio (Ca:Mg)
  - Generally ranges from 2:1 to 4:1 (average 3:1).
  - Generally should not exceed 10:1 to 15:1.
  - Only a laboratory soil test will provide this information.

**How lime works...**

\[
\text{CaCO}_3 + 2\text{H}^+ \rightarrow \text{H}_2\text{O} + \text{CO}_2 + \text{Ca}^{2+}
\]

- Don’t add urea or ammonium fertilizers with liming materials, as N will be lost to the atmosphere.

\[
\text{NH}_4^+ + \text{OH}^- \rightarrow \text{H}_2\text{O} + \text{NH}_3
\]

**Lowering pH**

- To lower the pH of alkaline soils, or to increase the acidity of soils around acid-loving plants, add elemental S.

\[
2\text{S} + 3\text{O}_2 + 2\text{H}_2\text{O} \rightarrow 2\text{H}_2\text{SO}_4 \rightarrow 4\text{H}^+ + 2\text{SO}_4^{2-}
\]

**What about gypsum?**

- Gypsum (CaSO₄) is primarily used on sodic soils (high in sodium) occurring east of the Cascades.
  - Ca²⁺ replaces Na⁺, which is then leached from the soil by irrigation.
  - West of the Cascades?
Nutrient Availability

- Only ~ 2% of the nutrients utilized by plants are extracted from soil particles.
- Cation Exchange Capacity (CEC)...
  - is a measure of nutrient retention in soil.
  - is primarily determined by soil texture.
  - is affected to a small degree by organic matter.
  - is relatively constant over time.

Sand
- .05 to 2mm
- feels gritty

Silt
- .002 to .05 mm
- feels smooth

Clay
- less than .002 mm
- feels sticky

Cation Exchange Capacity (CEC)

The Nitrogen Cycle

1) proteins (from OM) → amino acids
2) amino compounds → NH$_4^+$ + NH$_3$(gas)

Steps 1 & 2 are collectively referred to as mineralization.

3) 2NH$_4^+$ + 3O$_2$ → 2NO$_2^-$ + 2H$_2$O + 4H$^+$

Ammonium Oxygen Nitrite Water Acidity

This reaction is acidifying!

4) 2NO$_2^-$ + O$_2$ → 2NO$_3^-$

Nitrite Oxygen Nitrate

Steps 3 & 4 are known as nitrification.

Root-nodulating Rhizobia bacteria found in leguminous crops (e.g., peas, vetch, clover) are capable of fixing atmospheric N$_2$ in the soil.

Nitrogen can also be lost to the atmosphere through processes such as denitrification.

Always incorporate N fertilizers!

Remember, don’t add urea or ammonium fertilizers with liming materials!

Here’s another example of N cycling in the soil:

Bacteria have a C:N of ~5:1 (narrowest known)

Protozoans have a C:N of ~30:1

Protozoans release excess N after consuming bacteria.

Adding N can result in a decrease in OM due to blooming bacterial populations.
The Nitrogen Cycle in Review

- The N cycle is driven by the activity of soil microbes.
- The activity of those same soil microbes is controlled by environmental factors such as temperature and moisture.
- Thus the N cycle is equally dependent upon the same environmental factors that control the activity of soil microbes.

The phosphorus cycle in soil


Potassium

- Often Deficient
- Occasionally Deficient
- Seldom Deficient

Soil Fertility

- So, are the nutrients in your soil deficient, or are they just unavailable?
- If that is your question, soil testing is the answer!
Nutrient toxicities & luxury consumption

Too much:
- N: results in excessive foliar growth at the expense of flowering and fruit production.
- P: generally little or no effect; may induce micronutrient deficiencies with extreme excess.
- K: often results in “burning” of leaves around the edges.
- Ca: generally associated with high pH, which results in micronutrient deficiencies.
- Mg: may interfere with Ca uptake.
- S: generally no effect.
- B: death of interveinal tissues of leaves.
- Micros: generally associated with low pH.

Soil Testing

- “A soil sample weighing approximately 1/2 pound is used to represent from 2 to 40 million pounds of soil in the field.”
- To assure that your sample is truly representative, take a separate sample from each area that differs in topography or past management practices.
- Take 15 to 20 subsamples per sampling from the surface to a depth of 6-9 inches.

When do I take a soil sample?

- Always sample at the same time of year.
- Fall is a good time to sample, because slow-acting amendments that need to be added, such as lime, will have plenty of time to take effect over the winter.
- Maintain good records!

Interpreting Soil Test Results

- SMP buffer pH
  - SMP ~ Shoemaker, McLean & Pratt
  - The SMP buffer test measures a soil’s reserve acidity, which is proportional to CEC & texture.
  - While soil pH indicates whether you need to add lime or not, only the SMP buffer pH indicates how much lime you need to add.
  - Only a laboratory soil test will provide this information.
Interpreting Soil Test Results

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Units</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Excessive</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>ppm</td>
<td>&lt;20</td>
<td>20-40</td>
<td>40-100</td>
<td>&gt;100</td>
</tr>
<tr>
<td>K</td>
<td>ppm</td>
<td>&lt;150</td>
<td>150-250</td>
<td>250-800</td>
<td>&gt;800</td>
</tr>
<tr>
<td>Ca</td>
<td>ppm</td>
<td>&lt;1000</td>
<td>1000-2000</td>
<td>&gt;2000</td>
<td>N/A</td>
</tr>
<tr>
<td>Mg</td>
<td>ppm</td>
<td>&lt;80</td>
<td>80-180</td>
<td>&gt;180</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutrient</th>
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<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Excessive</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>meq/100 g</td>
<td>&lt;0.4</td>
<td>0.4-0.6</td>
<td>0.6-2.0</td>
<td>&gt;2.0</td>
</tr>
<tr>
<td>Ca</td>
<td>meq/100 g</td>
<td>&lt;5</td>
<td>5-10</td>
<td>&gt;10</td>
<td>N/A</td>
</tr>
<tr>
<td>Mg</td>
<td>meq/100 g</td>
<td>&lt;0.5</td>
<td>0.5-1.5</td>
<td>&gt;1.5</td>
<td>N/A</td>
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</table>

Fertilizer Guides on the Web

- [http://extension.oregonstate.edu/catalog/](http://extension.oregonstate.edu/catalog/)
  - Choose the link for either “Agriculture” or “Gardening”
- [http://nwrec.hort.oregonstate.edu/vegindex.html](http://nwrec.hort.oregonstate.edu/vegindex.html)

Fertilizers

- Organic vs. inorganic/synthetic: does it matter?
  - The answer is yes…and no.
  - The most important aspect is that we realize the differences and understand the advantages and limitations of each.

Definitions of “Organic”

- 1) Naturally occurring
- 2) Living, or once living
- 3) Carbon-based
  - a) Naturally occurring
  - b) Synthetic
  - c) Urea (H₂N)₂CO…which is it?

Organic: Advantages

- Slow release
  - Requires fewer applications
  - Reduced risk of over-fertilization
- Can be cheap (manure)
- Recycles products that would otherwise become waste (compost, manure)
- Feeds soil microbes (OM)
Organic: *Disadvantages*

- Usually very expensive (packaged blends)
- Can be difficult to apply (manure)
- Low analysis means large amounts are required.
- Complete blends often only contain small amounts of one or more nutrients.

Inorganic/Synthetic: *Advantages*

- Relatively cheap.
- Easy to apply.
- High analysis means small amounts are required.
- Fast acting, so plant response is quick.
- Complete blends (and custom blends) are easy to come by.

Inorganic/Synthetic: *Disadvantages*

- Accidental over-fertilization is easy.
- Production usually creates, rather than prevents, waste.
- Production requires large energy inputs.
- Amount and composition of fillers usually are not specified.
  - Fillers are used to achieve low analyses and custom blends and usually include lime or gypsum.

The Organic Debate in Review

- The choice is theirs, so don’t try to make it for them!
- On the other hand, don’t allow customers to be uninformed either!

Fertilizers: the Label

- The analysis, or grade, represents the amount of N, P & K in a fertilizer.
- Complete fertilizers contain N, P & K.
- Other nutrients are listed on labels in small print.

What’s not on the label?

- The guaranteed analysis will never add up to 100%. This is primarily because C, H and/or O are present too.
  - Example: ammonium sulfate, 21-0-0, \((\text{NH}_4)_2\text{SO}_4\), contains 21% N, 24% S, 6% H and 49% O by weight.
- Fillers may also be present, especially in products with low analyses or specialty blends.
Useful Conversions
• # nutrient per area → # fertilizer per area
  • (# nutrient recommended)/(% nutrient in fertilizer) x 100%
• #/A → #/1000 ft²
  • divide by 43.56
• #/A → #/100 ft²
  • divide by 435.6
• 1 # of fertilizer ≈ 2 cups (32 Tbsp)

Practice Calculation
• A client brings you the following soil test results and asks you how much 5-10-10 she should apply for her new 5’ x 20’ strawberry patch:
  • Soil test P: 30 ppm
  • Soil test K: 175 ppm
  • Slides 74 and 85 provide almost all the information you need to answer your client’s question…
  • You also need to know that a new planting of strawberries requires 40 pounds of nitrogen per acre.

Practice Calculation
• Step 1: determine how much P & K are needed. From slide 74...
  30 ppm soil test P…
  80 #/A P₂O₅
  175 ppm soil test K…
  80 #/A K₂O

Practice Calculation
• Step 2: determine how much fertilizer this amounts to. From slide 85...
  80 #/A + 10% x 100% =
  800 #/A 5-10-10
  • Note: since both P & K are required in the same amount (80 #/A), and since the fertilizer contains the same amount of each (10%), this rate applies to both P & K.
  • Also, since the amount of N needed (40 #/A) is half the amount of P & K needed, and since the fertilizer contains half as much N as it does P & K, 800 #/A of 5-10-10 also satisfies the N requirement of the new crop.

Practice Calculation
• Step 3: determine how much fertilizer this amounts to per 100 ft². From slide 85...
  800 #/A + 435.6 =
  1.84 #/100 ft² 5-10-10
• Step 4: determine how much fertilizer this amounts to by volume. From slide 85…
  1.84 #/100 ft² x 2 cups/# =
  3 2/3 cups/100 ft² 5-10-10