Nutrient Management for Crops, Soil, and the Environment

Research-based Practical Guidance for Organic and Transitioning Farmers

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Organic Farming Research Foundation

Organic Farmer Research Priorities

Soil Health – 74%
Nutrient management – 66%
Topics include:
• Matching crop needs
• Minimizing nutrient losses.
• Nutrient efficient cultivars.
• Nutrients, soil life, and pest resistance.
Download full report at http://ofrf.org/.
Soil Health and Crop Nutrition

Healthy, living soils:
- Retain and recycle plant nutrients.
- Nourish crops from nutrient reserves in soil organic matter (SOM).
- Minimize nutrient losses, protect water quality.

“Feed the soil, and the soil will feed the plant.”

Nutrient Dynamics in Living Soil

Inputs:
- Plant residues
- Manure
- Fertilizers
- Amendments

Soil Organic Matter
Soil Minerals

Soil Life
Two-way Exchange

- Plants deliver 10 – 30% of their photosynthetic product to soil life.
- Beneficial microbes in the rhizosphere (root zone) enhance plant nutrition and health.
- Mycorrhizal fungi assist nutrient and moisture uptake and protect host plants from disease.

Crop Nutrient Sufficiency

Healthy soil provides:
- Adequate nutrient reserves; favorable pH.
- Abundant and balanced soil life.
- Deep, open soil profile, allowing roots to explore large volume of soil.
Causes of Crop Nutrient Deficiency

Crop nutrition suffers when soil nutrients are depleted (left), when soil life is scarce or stressed (center), or when soil compaction restricts root growth (right).

Soil Health and Plant Nutrients

Building soil health enhances nutrient release from organic matter. Fast-release fertilizers stimulate crops but can undermine soil health.
20th Century Nutrient Management

- “Feed the plant”:
  - Synthetic NPK
  - Other nutrients if needed
  - Lime for acid pH
- Soil life disregarded
- Rates determined by:
  - Expected crop response based on soil test
  - A little more added for “insurance.”

Organic Nutrient Management, Step 1: Understand Essential Crop Nutrients

Major Nutrients
- Nitrogen (N) – nitrate anion ($NO_3^-$) or ammonium cation ($NH_4^+$)
- Phosphorus (P) – phosphate anions ($HPO_4^{2-}$ and $H_2PO_4^-$)
- Potassium (K) – cation ($K^+$)

Secondary Nutrients
- Calcium (Ca) – cation ($Ca^{2+}$)
- Magnesium (Mg) – cation ($Mg^{2+}$)
- Sulfur (S) – sulfate anion ($SO_4^{2-}$)
Essential Micronutrients

Essential for crops:
- Boron (B) – borate anion
- Copper (Cu) – cation or chelate
- Zinc (Zn) – cation or chelate
- Iron (Fe) – cation or chelate
- Manganese (Mn) – cation or chelate
- Molybdenum (Mb) – molybdate anion
- Nickel (Ni) – cation or chelate
- Sodium (Na) – cation (Na⁺)
- Chlorine (Cl) – anion (Cl⁻)

Important for animal and human nutrition:
- Cobalt (Co), Selenium (Se), Chromium (Cr).

How Soil Life and Soil Organic Matter Hold and Deliver Nutrients to Plants
Organic Nutrient Management, Step 2
*Feed the Soil Life a “Balanced Diet.”*

- Cover crops, green manures
- Compost and manure
- Crop residues
- Organic mulches

Organic Nutrient Management, Step 3: *Test the Soil*

A standard soil test reports:
- pH (acidity)
- Plant-available P, K, Ca, Mg, some micronutrients
- % total SOM
- Cation exchange capacity (CEC)

Additional tests available through some labs:
- Nitrate-N, potentially mineralizable organic N
- Active SOM
- Soil microbial respiration
Organic Nutrient Management, Step 4: Provide Supplements as Needed

Use organic and natural mineral nutrient sources (right) to:

- Restore depleted soils
- Remedy deficiencies
- Adjust soil pH
- Sustain crop yields
- Replenish nutrients removed in harvest

Nutrient Management Challenge #1: Translating Soil Tests to “Organic”

Standard soil test recommendations include:

- Lime based on soil pH and buffer index.
- N based on crop only.
- P and K based on soil test P and K and crop grown.

Challenges for organic producers:

- Complex nature of biological nutrient cycling.
- Variable NPK contents of manure, compost, etc.
- Lack of research in organically managed soils.
Soil life can modify crop response to applied nutrients.

**Nutrient Management Challenge #2: Nitrogen**

Organic crops are often N limited when:
- Soil life is depleted or out of balance.
- The field is newly transitioned to organic.
- N-poor residues like straw are tilled in.
- An early spring heavy N feeder is grown.
- Excessive rains leach soil N.
- Cold or dry soil slow biological N release.
- Crop cultivars have been developed in and for high-input conventional systems.

N deficiency in spring-planted organic broccoli.
Nitrogen and Soil Health: Potential Tradeoffs

- Cover crops with reduced tillage build soil health, but can slow N mineralization and limit crop yields.
- Providing N in concentrated forms such as poultry litter can:
  - Leach nitrate-N to groundwater.
  - Increase N\textsubscript{2}O emissions.
  - Accelerate SOM decomposition.
  - Deter beneficial plant root-microbe interactions.

Nitrogen is Challenging for All Farmers …
... Especially When Soil Life is Depleted.

Matching N Release to Crop Demand

Cumulative crop N

Relative N release or uptake

Days after planting

Ideal

Too fast

Too slow
**Delivering the N Where it is Needed**

Soil Life

Organic N in Active SOM

Slow-release N

\[ \text{Organic N} \rightarrow \text{NH}_4^+ \rightarrow \text{NO}_3^- \]

Nutrient management challenge #3: *Phosphorus*

- Crops use 5 – 8 lb N for every 1lb P.
- Manure and compost provide 2 – 3 lb N per lb P.
- Using manure and compost to meet crop N needs can build excess soil P and:
  - Release P into runoff.
  - Inhibit mycorrhizal fungi.
  - Tie up micronutrients.

Heavy compost used to rebuild depleted soil can accrue P surpluses.
Nutrient management challenge #4: **Intensive Multi-cropping, High Tunnels**

Intensive multiple-cropping can:
- Deplete N and K.
- Consume SOM through tillage.
- Reduce residue return to the soil.

Using large amounts of compost to replenish soil can:
- Build up P, other nutrients.
- Build up salts in high tunnel.

Goals of Organic Nutrient Management

- Maintain yields and quality.
- Protect soil health, water quality, and climate.
- Build soil capacity to meet crop needs with minimal input.
- Remedy soil nutrient deficiencies and imbalances.
- Replenish nutrients removed in harvest.
- Avoid or draw down nutrient excesses.
### Replenishing Nutrients: Vegetable Crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield t/ac</th>
<th>Lb/ac removed: (N, P, K)</th>
<th>Rec. rate, lb/ac³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broccoli</td>
<td>5.6</td>
<td>20 – 53, 7, 36</td>
<td>175, 22, 42</td>
</tr>
<tr>
<td>Lettuce</td>
<td>12.0</td>
<td>20 – 62, 7, 60</td>
<td>100, 44, 83</td>
</tr>
<tr>
<td>Onion</td>
<td>19.4</td>
<td>28 – 73, 11, 60</td>
<td>85, 22, 42</td>
</tr>
<tr>
<td>Squash</td>
<td>15.0</td>
<td>27 – 52, 8, 96</td>
<td>85, 22, 83</td>
</tr>
<tr>
<td>Tomato</td>
<td>13.2</td>
<td>14 – 37, 6, 54</td>
<td>70, 44, 83</td>
</tr>
<tr>
<td>Mixed compost (1-1-1) at 5 t/ac adds:</td>
<td></td>
<td></td>
<td>100, 44, 83</td>
</tr>
<tr>
<td>Poultry litter (5-4-3) at 1 t/ac adds:</td>
<td></td>
<td></td>
<td>100, 35, 50</td>
</tr>
</tbody>
</table>

### Replenishing Nutrients: Field Crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield</th>
<th>Nutrient removal, lb/ac³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn, grain</td>
<td>150 bu/ac</td>
<td>150, 29, 35</td>
</tr>
<tr>
<td>Soybean, grain</td>
<td>50 bu/ac</td>
<td>190ᵃ, 18, 34</td>
</tr>
<tr>
<td>Wheat, grain</td>
<td>80 bu/ac</td>
<td>128, 21, 30</td>
</tr>
<tr>
<td>Grass hay</td>
<td>5 t/ac</td>
<td>185, 24, 195</td>
</tr>
<tr>
<td>Corn, silage</td>
<td>5 t (dry)/ac</td>
<td>170, 31, 183</td>
</tr>
<tr>
<td>Compost (1-1-1), 5 t/ac</td>
<td>100, 44, 83</td>
<td></td>
</tr>
<tr>
<td>Poultry litter (5-4-3), 1 t/ac</td>
<td>100, 35, 50</td>
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</tr>
</tbody>
</table>

ᵃ Much of this N is fixed by Bradyrhizobium symbiosis.
Grain Crops May Need Little Fertilizer on Healthy Soils

- Corn-soy-wheat + cover crops
- SC coastal plain sandy soils
- With / without recommended P and K

Results
- Cover crops build SOM
- Full grain yields without added P or K, and 50% recommended N
- Little change in soil P or K

“Living soil changes everything”
Robin Kloot, 2017 Organic Agriculture Research Symposium, Lexington, KY.

Broccoli: a Nitrogen Hog?

In California, organic broccoli required 220 lb N/ac for optimum yield.

This much organic N:
- Leached ~180 lb N/ac.
- Emitted 17-42 lb/ac N$_2$O.
- Leached another 100 lb N/ac from tilled broccoli residues.

(U. California, Santa Cruz)

At Virginia Tech, organic broccoli required 150 lb N/ac in addition to cover crop, for maximum yield.
Tight N Cycling in Organic Tomato

3 types of organic tomato fields in CA:

- N deficient – low soluble N, low yield.
- N saturated – high soluble N, high yield and high leaching risk.
- Tight N cycling – low soluble N, high yield, minimal leaching risk.

➢ Diverse organic inputs with low to high C:N ratio promoted tight nutrient cycling.

(U. California at Santa Cruz)

Vigorous tomatoes grown on low-N compost.

Adjust Amendment Rates to Soil Test P

Obtain soil test and total nutrient analysis for compost or manure.

- On low-P soil, apply compost to meet N and K needs and build P.
- If soil P is optimum, apply compost to maintain P; grow legumes for N.
- For very high or surplus soil P, use compost sparingly if at all.

Remember: a little compost goes a long way for soil health.
Cover Crops: a Vital Tool for Organic Nutrient Management

Cover crops:
• Feed soil life, build SOM.
• Fix N (legumes).
• Absorb and retain soluble N.
• Retrieve nutrients from subsoil, protect water quality.
• Enhance plant-available soil P (legumes, buckwheat) and K (grasses) when needed.
• Never aggravate P or K excesses.

Clockwise from top left: pearl millet, hairy vetch, buckwheat, four-way mix.

Cover Crop Types and N Dynamics

Mix and match cover crops to manage nitrogen for production and environmental goals.

<table>
<thead>
<tr>
<th></th>
<th>LEGUME</th>
<th>CRUCIFER</th>
<th>MIX</th>
<th>GRASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>N fixation potential</td>
<td>High</td>
<td>None</td>
<td>High</td>
<td>Limited</td>
</tr>
<tr>
<td>N recovery</td>
<td>Low-mod</td>
<td>Very high</td>
<td>Mod-high</td>
<td>High</td>
</tr>
<tr>
<td>Residue C:N ratio</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Available N release</td>
<td>Rapid</td>
<td>Rapid</td>
<td>Slow</td>
<td>N tie-up</td>
</tr>
<tr>
<td>N leaching &amp; N₂O risk</td>
<td>High</td>
<td>High</td>
<td>Low-mod</td>
<td>Low</td>
</tr>
</tbody>
</table>
Managing SOM: a Balancing Act

“Management of SOM to enhance soil quality is a key determinant of successful organic farming, which involves balancing two ecological processes: mineralization of carbon (C) and nitrogen (N) in SOM for short term crop uptake, and sequestering C and N in SOM for long term maintenance of soil quality.”

Delate et al., 2015. Sustainable Agric. Res. 4(3): 5-14.(Emphasis added)
Zone Tillage: Releasing Nutrients Where They Are Needed

- Ridge tillage promotes early-season nutrient release in crop rows, leaving between-row soil undisturbed.
- High-residue cultivator moves organic residues into crop row, providing additional fertility.
- Other ways to concentrate nutrient release in the “grow zone” include:
  - Strip tillage.
  - Band application of fertilizer
  - In-row drip fertigation

Zone Planting for Nutrient Management

- Planting legumes or crucifers in future crop rows with grasses in alleys can promote efficient use of N released from cover crop residues.
- Strip or zone tillage (grass alleys mowed or rolled) can further reduce N losses.
Summary: Best Organic Nutrient Management Practices

- Build and maintain healthy soil, grow cover crops.
- Use perennial sod crops to restore soil fertility.
- Test your soil and organic amendments regularly.
- Use crop foliar analyses to supplement soil analyses.
- Adjust manure/compost rates according to soil P.
- Use organic nutrient budgeting tools.
- Do side-by-side trials with/without organic fertilizers.
- Promote nutrient release in crop row (zone management).

Organic Nutrient Management Research Priorities

- Evaluate responses of a range of crops to N, P, K, and other nutrients in organic systems.
- Develop decision tools for organic N rates, considering crop, preceding crop, climate, soil type and soil condition.
- Explore tight N cycling in a wider range of crops, soils, and climates.
- Fine tune cover crop management to minimize N$_2$O.
- Breed and develop new crop cultivars for nutrient efficiency, and effective partnership with soil life.
Download the Soil Health and Organic Farming Guides at [www.ofrf.org](http://www.ofrf.org).

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Questions?

The Soil Food Web