Nutrient management strategies for organic vegetable production

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Outline:
- Crop macronutrient requirements
- P and K evaluation and management
- N cycling in organic soils
- In-season N diagnostics (soil and plant)
- Irrigation influence on N management
How much N/P/K do vegetable crops need?

Typical seasonal nutrient uptake of conventionally grown, high-yield vegetable crops in California:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Seasonal crop uptake (lb/acre)</th>
<th>% nutrient removal with harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>broccoli</td>
<td>250-350</td>
<td>40-50</td>
</tr>
<tr>
<td>Brussels sprouts</td>
<td>350-500</td>
<td>40-60</td>
</tr>
<tr>
<td>cabbage</td>
<td>280-380</td>
<td>40-50</td>
</tr>
<tr>
<td>cantaloupe</td>
<td>150-200</td>
<td>15-25</td>
</tr>
<tr>
<td>carrot</td>
<td>150-220</td>
<td>25-40</td>
</tr>
<tr>
<td>cauliflower</td>
<td>250-300</td>
<td>40-45</td>
</tr>
<tr>
<td>celery</td>
<td>200-300</td>
<td>40-60</td>
</tr>
<tr>
<td>head or romaine lettuce</td>
<td>120-160</td>
<td>12-16</td>
</tr>
<tr>
<td>baby lettuce</td>
<td>60-70</td>
<td>5-7</td>
</tr>
<tr>
<td>onion</td>
<td>150-180</td>
<td>25-35</td>
</tr>
<tr>
<td>pepper (bell)</td>
<td>240-350</td>
<td>25-50</td>
</tr>
<tr>
<td>potato</td>
<td>170-250</td>
<td>30-40</td>
</tr>
<tr>
<td>processing tomato</td>
<td>220-320</td>
<td>35-45</td>
</tr>
<tr>
<td>spinach</td>
<td>90-130</td>
<td>12-18</td>
</tr>
</tbody>
</table>

- The high end of these ranges represents the main season production, the lower end represents less favorable conditions.
- Organic crops are likely to be lower yield, and lower nutrient concentration; seasonal organic nutrient uptake perhaps 20-25% less than these tabled values??
What is the timing of crop nutrient uptake?

Harvest vegetative crops

Harvest fruiting crops
What is the timing of crop nutrient uptake?

![Graph showing the fraction of final crop nutrient uptake over time from planting to harvest.]

- 3-6 lb N/acre/day
- 0.5-1.5 lb P$_2$O$_5$/acre/day
- 4-9 lb K$_2$O/acre/day
P and K management:
• Soil supply is ‘buffered’, and tends not to change quickly over time
• Therefore, the foundation of effective management is soil testing and appropriate preplant application

Phosphorus test methods:
• Olsen (bicarbonate)
• Bray
• Mehlich
These methods give very different values, and are not well correlated

Potassium test methods (‘exchangeable K’)
• Ammonium acetate
• Mehlich
Both methods give similar values
P and K sufficiency levels (the level above which fertilization will not increase crop yield) varies widely among crops...
Interpreting soil P test results*:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Olsen P (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>crop response likely*</td>
</tr>
<tr>
<td>lettuce and celery</td>
<td>&lt; 40</td>
</tr>
<tr>
<td>other cool-season vegetables</td>
<td>&lt;25</td>
</tr>
<tr>
<td>warm-season vegetables (tomato, pepper, potato, cucurbits)</td>
<td>&lt; 15</td>
</tr>
</tbody>
</table>

*regardless of soil temperature
** response more likely in soils < 60°F

Interpreting soil K test results*:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Exchangeable K (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>crop response likely</td>
</tr>
<tr>
<td>celery</td>
<td>&lt; 150</td>
</tr>
<tr>
<td>other cool-season vegetables</td>
<td>&lt;100</td>
</tr>
<tr>
<td>potato, tomato, pepper</td>
<td>&lt;150</td>
</tr>
<tr>
<td>cucurbits</td>
<td>&lt; 80</td>
</tr>
</tbody>
</table>

*High-yield conventional production
Don’t organic soils provide more P and K than conventional soils at the same soil test level?

- higher degree of mycorrhizal association increases P availability
- better soil structure may increase rooting density, which increases both P and K availability

These effects are modest, and most important at marginal levels of soil fertility; most growers are uncomfortable managing on the margins ...
Preplant application of P and K is generally advised; is there any justification for in-season application?

- Probably not for P
- K sidedressing or fertigation may be appropriate for K-fixing soils (rare on the coast, common in the Central Valley), or in very sandy soils
P and K application vs. crop nutrient uptake:

- Crop uptake ratio of N : P<sub>2</sub>O<sub>5</sub> is typically between 3:1 and 5:1
- Crop uptake ratio of N : K<sub>2</sub>O is typically between 1:1.2 to 1:1.5
- Ratios of *available* N:P:K in organic nutrient sources are often far out of balance

In manure-based material:
- ‘available’ N:P<sub>2</sub>O<sub>5</sub> ratio often < 1:2
- ‘available’ N:K<sub>2</sub>O ratio often > 1:3
Preplant soil testing provides limited information to guide N management:
• Predicting N mineralization potential from soil properties is problematic
• The full contribution of recently applied or incorporated materials is not yet clear
• The potential loss of residual NO$_3$-N by irrigation for crop establishment is large
Effective organic N management requires an understanding of N cycling through soil organic matter (SOM).

- Labile SOM: Active fraction, ~2 year old
- Resistant SOM: ~5 to 40 years old
- Stable SOM: >1000 years old
- Particulate organic matter
  - Microbial biomass
- Resistant Organic Matter
- Very Stable Organic Matter
Contribution of soil organic pools to nitrogen availability

- Increasing labile SOM through organic matter additions increases $N$ mineralization potential ($N_{\text{min}}$)
Net N mineralization in 8-10 weeks at 70-75 °F:

- N concentration is the best predictor of N availability because N concentration drives the C:N ratio
- Materials < 2% N provide little, if any, N
- High N materials (feather meal, blood meal, guano, fishery wastes) mineralize > 50% of their N

Data adapted from:
Gale et al., 2006. J. Environ. Qual. 35:2321-2332
Liquid organic fertilizers, and ‘blended’ fertilizers, have faster $N_{\text{min}}$ than their % N suggest:

• The N concentration of the feedstock material is diluted with water or other material

$N_{\text{min}}$ of liquid organic fertilizers over a 4 week incubation:

Hartz, unpublished data
How does soil temperature affect N mineralization of amendments and fertilizers?

- lower temperature does slow microbial processes; general rule of thumb is that the rate of microbial processes double with each 18 °F rise in temperature

- however, since organic materials contain both labile and resistance N compounds, the effect of temperature on $N_{\text{min}}$ is not this great
How does soil temperature affect N mineralization of amendments and fertilizers?

- lower temperature does slow microbial processes
- however, highly labile N will be mineralized relatively quickly regardless of temperature; once highly labile N is mineralized additional $N_{\text{min}}$ is slow, regardless of temperature

Mean of 4 high-N organic fertilizers, Hartz and Johnstone 2006. HortTechnology 16:39-42
Given current organic management practices in California, how big an increase in soil N mineralization potential is likely?

- Measureable, but not large

Lab incubation of Central Valley soils in vegetable rotations:

- Organic soil averaged 1.3 lb N/A/day (2.1% of organic soil N)
- Conventional soil averaged 1.0 lb N/A/day (1.7% of organic soil N)

Timing of $N_{\text{min}}$:

- Soil tillage, or addition of organic material, causes a burst of soil microbial activity, and $N_{\text{min}}$
- Within weeks the microbial activity slows, and $N_{\text{min}}$ drops to a much lower rate

Lab incubation at 68 °F, Hartz, unpublished data
Implications for N management:
- The majority of the N contribution from cover crops, prior crop residues, and preplant applied amendments will be mineralized within 4-6 weeks after incorporation.
- Post-establishment soil nitrate sampling [also called ‘presidedress soil nitrate sampling (PSNT)] takes the guesswork out of estimating these N contributions.
- After crop establishment, $N_{\text{min}}$ from all sources will probably not be sufficient to keep up with crop N demand; you must start the season with a substantial ‘N balance’ or else risk later-season N deficiency.
Importance of beginning the season with substantial soil NO$_3$-N:

In 22 organic processing tomato fields

- Soil NO$_3$-N sampled every 2 weeks from 3 weeks after transplanting (WAT)
- Whole plant N concentration at 11 WAT measured to assess crop N sufficiency

Soil NO$_3$-N highly variable among fields, declines over time:

Degree of variability in soil NO$_3$-N at 3 WAT is of agronomic significance:

How much N does this represent?

- 40 lb/acre
- 240 lb/acre

Low early-season soil NO$_3$-N predicted later season N deficiency:

How to use early-season soil nitrate (NO$_3$-N) sampling in organic production?

- How deep to sample?
- What is the ‘action threshold’ for N application?
- How late in the season can organic fertilizer application be useful?
How deep to sample?

Surprisingly, there tends to be a reasonably good correlation between NO$_3$-N in the top foot and NO$_3$-N in the second foot of soil.
What is the ‘action threshold’ for soil NO$_3$-N?
• for processing tomato < 10-15 PPM NO$_3$-N was problematic
• high density leafy greens, and Brassica crops, need a higher level of residual NO$_3$-N
How late in the season can N fertilizer application be useful?

- High-N fertilizers (> 6% N) are likely to mineralize 50% or more of their N content in 2-3 weeks after incorporation.
Lab analysis is more accurate, but there is an on-farm ‘Nitrate Quick Test’ that can semi-quantitatively estimate soil NO$_3$-N.
Leaf analysis is of limited value in fine-tuning fertilizer application:

- Correlation between soil NO$_3$-N and leaf N is poor until the crop N uptake rate is high

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End-of-season tissue sampling can provide guidance for next season:

Processing tomato leaf N from 20 commercial fields:
What about petiole NO$_3$-N analysis?

- Very low petiole NO$_3$-N at 3-4 weeks post-establishment may be a useful predictor of future N deficiency; unfortunately, a ‘sufficient’ NO$_3$-N level does not confirm soil N sufficiency.
- Later season petiole NO$_3$-N generally not useful, as organic systems often have very low values, even where N is sufficient.
Irrigation management can make or break organic N management

- Each acre inch of leaching will commonly carry at least 10 lb of NO$_3$-N below the root zone; loss potential is greatest in the early part of the crop cycle
Questions?