The Long-Term Effects of High $\text{NH}_4^+ / \text{NO}_3^-$ Ratios on Wheat Growth and Nitrification in Hydroponic Culture

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Plants, Soils, & Biometeorology
All Cells Must Maintain Charge Balance

\[ \text{ROOT} \]

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

\[ \text{OH}^- \rightarrow \text{H}^+ \]

• Raises pH by 1-2 units
• Lowers pH by 1-2 units
Techniques for Alleviating NH$_4^+$ Toxicity

- Control rhizosphere acidity by addition of a base (Henry and Raper, 1989)
Ca$^{2+}$ K$^+$

Favors cation uptake

• Inhibits cation uptake

NO$_3^-$

NH$_4^+$

Ca$^{2+}$ K$^+$

ROOT
Techniques for Alleviating NH$_4^+$ Toxicity

- Control rhizosphere acidity by addition of a base (Henry and Raper, 1989)
- Alleviate K$^+$ deficiencies by adding excess K$^+$ (Ajayi et al., 1970)
Ca^{2+} and Cl^{-} favor cation uptake, while NO_{3}^{-} inhibits cation uptake.

Favors cation uptake: NO_{3}^{-}, Ca^{2+}, SO_{4}^{2-}, Cl^{-}

Inhibits cation uptake: NH_{4}^{+}, Ca^{2+}, SO_{4}^{2-}, Cl^{-}
Techniques for Alleviating NH$_4^+$ Toxicity

- Control rhizosphere acidity by addition of a base (Henry and Raper, 1989)
- Alleviate K$^+$ deficiencies by adding excess K$^+$ (Ajayi et al., 1970)
- Providing Cl$^-$ (counter ion) may increase Ca$^{2+}$ uptake (Koenig and Pan, 1996)
Assimilation in either root or leaves must be assimilated in the root in the root.
Techniques for Alleviating $\text{NH}_4^+$ Toxicity

- Control rhizosphere acidity by addition of a base (Henry and Raper, 1989)
- Alleviate $\text{K}^+$ deficiencies by adding excess $\text{K}^+$ (Ajayi et al., 1970)
- Providing $\text{Cl}^-$ (counter ion) may increase $\text{Ca}^{2+}$ uptake (Koenig and Pan, 1996)
- Prevent carbohydrate deficiencies by maintaining constant temperature and light levels (Lavoie et al., 1992)
Objectives

• Determine the long-term effects of high NH$_4^+$ on growth, yield, and nutrient uptake
• Determine the importance of SO$_4^{2-}$ vs. Cl$^-$ as counterbalancing ions with NH$_4^+$
• Quantify nitrification
Automated Nutrient Control System

Randomized

15% NH₄⁺
80% NH₄Cl
80% (NH₄)₂SO₄

pH Control

NH₄⁺ & Nutrient Maintenance

NO₃⁻ Control
2 Replicate Trials

Root Zone Treatments

15% NH₄⁺
80% NH₄Cl
80% (NH₄)₂SO₄

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Vegetative Biomass</th>
<th>Yield (g m⁻²)</th>
<th>Harvest Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Veery-10</td>
<td>5000</td>
<td>500</td>
<td>0.40</td>
</tr>
<tr>
<td>USU-Line 10</td>
<td>5000</td>
<td>500</td>
<td>0.40</td>
</tr>
</tbody>
</table>

p = 0.70

p = 0.99

ns

p = 0.04

ns

p = 0.99

a

b b b b
2 Replicate Trials

Root Zone Treatments

- 15% NH₄⁺
- 80% NH₄Cl
- 80% (NH₄)₂SO₄

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Veery-10</th>
<th>USU-Line 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed % Ca</td>
<td>p=0.08</td>
<td>ns</td>
</tr>
<tr>
<td>Vegetative Biomass % Ca</td>
<td>p=0.004</td>
<td>a</td>
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</table>

Values with different letters indicate significant differences (p<0.05)
Nitrification

\[ \text{NH}_4^+ \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^- \]

Ammonium oxidizers such as *Nitrosomonas*  
Nitrite oxidizers such as *Nitrobacter*

- Microbial optimum pH 6.6-8.0  
- Plant optimum pH 5.8
Nitrification in Hydroponics

• Padgett and Leonard reported that conversion of $\text{NH}_4^+$ to $\text{NO}_3^-$ by nitrifying organisms is a significant problem in $\text{NH}_4^+$-based solutions in hydroponics. (Padgett and Leonard, *Plant Physiology* (1993))

• Nitrification would be beneficial in NASA Advanced Life Support.
Materials And Methods
(Nitrification Study)

- 3 x 2 Factorial (4 Reps)
  - pH 5.8 or 7.0
  - Inoculated or not inoculated
  - Planted or not planted

- $^{15}\text{NO}_3^-$ addition to quantify nitrification rates (isotopic dilution)
Isotopic Dilution

49-50 Days after Inoculation

\[^{14}\text{NH}_4^{+} \xrightarrow{\text{Nitrifiers}} {^{14}\text{NO}_3^{-}} \xrightarrow{} {^{15}\text{NO}_3^{-}}\]

\[\rightarrow {^{14}\text{NO}_3^{-}} \rightarrow {^{15}\text{NO}_3^{-}}\]
<table>
<thead>
<tr>
<th>pH 5.8</th>
<th>Inoculated</th>
<th>GPR (µmol L(^{-1}) hr(^{-1}))</th>
<th>GCR (µmol L(^{-1}) hr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planted</td>
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<td>9.10 (SD = 0.20)</td>
<td>15.09 (SD = 6.85)</td>
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<tr>
<td>Not</td>
<td>Inoculated</td>
<td>8.80 (SD = 0.38)</td>
<td>14.98 (SD = 7.92)</td>
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<tr>
<td>Not Planted</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Inoculated</td>
<td></td>
<td>18.83 (SD = 2.89)</td>
<td>11.39 (SD = 3.65)</td>
</tr>
<tr>
<td>Not</td>
<td>Inoculated</td>
<td>17.13 (SD = 3.51)</td>
<td>6.70 (SD = 7.09)</td>
</tr>
<tr>
<td>Not Planted</td>
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<table>
<thead>
<tr>
<th>pH 7.0</th>
<th>Inoculated</th>
<th>GPR (µmol L(^{-1}) hr(^{-1}))</th>
<th>GCR (µmol L(^{-1}) hr(^{-1}))</th>
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</thead>
<tbody>
<tr>
<td>Planted</td>
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<td>8.66 (SD = 3.05)</td>
<td>17.94 (SD = 4.73)</td>
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<tr>
<td>Not</td>
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<td>7.33 (SD = 0.50)</td>
<td>25.60 (SD = 11.27)</td>
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<tr>
<td>Inoculated</td>
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<td>28.58 (SD = 2.34)</td>
<td>10.70 (SD = 10.11)</td>
</tr>
<tr>
<td>Not</td>
<td>Inoculated</td>
<td>22.87 (SD = 3.69)</td>
<td>14.96 (SD = 11.80)</td>
</tr>
<tr>
<td>Not Planted</td>
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</table>
Conclusions

• Wheat can be grown in high NH$_4^+$ with little effect on growth and yield
• Counter ion had no effect on Ca$^{2+}$ uptake in these studies
• Inoculation with nitrifying microorganisms may help alleviate high NH$_4^+$ problems