Managing Inorganic Nitrogen Associated with Synthetic Fertilizers

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Consider complexity of N sources and fates in the soils and production systems:

- N additions come as synthetic fertilizers, crop residues, cover crops, manures and dairy lagoon water
- N removed via crop harvest, leaching & volatilization
- N can be tied up in organic forms that only slowly become available, or in microorganisms for eventual release
- released through mineralization at rates impacted by many factors (microbial populations, temperature, moisture, residue amounts)
- Soil organic matter breaks down & ammonium can be released for later transformation into nitrate
Components of an N application
“Decision Plan”

- Consider complexity of N sources and fates in the soils and production systems (continued):
  - Plants can take up both ammonium and nitrate forms of N, but in most agricultural soil conditions, nitrate is typically present in greater quantities than ammonium, so the focus is on measuring nitrate in soils
  - Where this may be a less accurate assumption (nitrate more prevalent than ammonium) could be when you are evaluating organic production fields, fields incorporating crops with high levels of organic matter, or with true slow-release specialty fertilizers.
N FORM IN THE SOIL – what happens after fertilize?

- If applied fertilizer N or mineralized OM N stayed in the form of ammonium ions (NH4+), it would be attached to the negatively charged soil particles and residue, and in that ammonium form:
  - Much less prone to loss through leaching, and
  - Wouldn’t be lost by denitrification (microbial conversion to N gas in saturated soils)

- However, the microbial process of **nitrification** (ammonia converted to nitrate) can readily occur over a period of weeks, resulting in much of the applied N converted to a form more susceptible to leaching.

- Once in nitrate form, **denitrification** (also a microbe dependent process) can convert nitrate to N gas, also subject to losses
Fertilizer N losses – what factors influence potential losses?

N FORM IN THE SOIL – what happens after fertilizer?

- Nitrification and denitrification processes are both influenced by soil & temperature conditions
  - **Nitrification**: temperature has important effects (warmer=faster)
  - **Denitrification**: temperature, soil water content (accelerates when saturated, anaerobic conditions exist)

- Keep in mind that conversion to nitrate form is not necessarily a bad thing ... and doesn’t necessarily mean N will be lost. However, N is more susceptible to losses (leaching, denitrification) in nitrate form. The amount of loss affected by:
  - the **leaching** losses occur with excess water movement below the root zone, and the
  - **denitrification** losses accelerate with saturated conditions (excess water, poor drainage)
Fertilizer N losses – what factors influence potential losses?

- **Fall or winter application for a spring-planted crop**
  - Past work would suggest that under typical winter rainfall and temperature conditions, most N in fertilizer applied in ammonia forms would be converted to nitrate by planting time in the spring – *one of the reasons why fall or early winter applications not recommended for a late winter or early spring planted crop*

- **Spring or late-winter application for spring-planted crop**
  - Potential for losses still affected by factors including:
    - **Amount of nitrate in soil** (affected by form of fertilizer applied, rate and timing of application, use of nitrification inhibitor)
    - **Amount of water moving through soil** (rainfall + irrigations) either on purpose (leaching) or naturally due to lack of storage capacity
    - **Duration of periods of saturation** of portions of soil profile
Components of an N application “Decision Plan”

- Evaluate N needs based on a realistic yield goal
  - Are yields limited by soil properties, hard to change? Or are improvements expected?
  - Realistic long-term averages helpful, adjust for current year conditions
  - Recognize that yield targets may keep changing:
    - May go up with need for higher yields and quality to cover escalating input costs
    - May be adjusted some years based on input limitations (ie. Low water allocation year, etc.)
  - Helpful to identify \textbf{N needs of crop per unit of yield} (ie. 3 lbs N/100 lbs grain, 55 lbs N/bale of cotton) rather than a set amount to produce a grain or cotton crop
Moving YIELD TARGETS?

Wheat – SJV Estimates
Yield 1990- 3 T, 2011- 3.75 to 5 T/A

Corn SJV Estimates
1990- Yields 5-6 T/A in 2011 6-8 T/A

Cotton -Yields in 1980- 2.2 to 2.75 Bales, 2000-2.5 to 3.5 Bales, 2011 – 3.25 to 4+bales
Components of an N application “Decision Plan”

- Consider a “credit” based on prior crop

  - Vegetable, field crop, alfalfa will differ, and potential organic N contributions will not fully show up in soil test nitrate evaluations

  - ESTIMATED AMOUNTS FOR CREDITS?
    - Need develop this information for CA Systems – or at least use as a basis for adjusting estimates
    - EXAMPLE: cotton N mgmt (next page)
Crop rotations and upper soil N

- Rotations likely to produce higher soil N during year cotton grown:
  - *Cotton grown in rotation with:*
    - Shallow-rooted vegetable crops
    - Garlic, processing tomatoes, field corn
    - First year after alfalfa

- Rotations likely to produce lower soil N during year cotton grown:
  - *Cotton grown in rotation with:*
    - Several prior years of cotton in many cases
    - Small grains
    - Safflower, sugar beets
Consider **efficiency of side-dress applications** within season as likely a little more directed, better positioned to be intercepted by the root system than applications of N made pre-plant or just after planting
- may consider a 5 to 10% lower rate based on this efficiency

**Avoid tendency to apply “just a little more”** than what you have calculated as necessary for the yield goal
- This “risk mitigation” or insurance approach in many years could increase the chance of losses below the root zone
Some fertilizer N characteristics with potential to impact handling, timing of use and losses

Anhydrous Ammonia:
- This form of applied N is generally considered relatively slow to convert to nitrate in the soil.
- As long as it is injected (shanked into soil) with proper concern for depth of application and closing the soil, it can be more stable and slower to convert to nitrate and be subject to leaching than some other N fertilizers.
- Free ammonia: Still have to be careful regarding losses, and it can be a hazardous material to handle if used improperly.
Some fertilizer N characteristics with potential to impact handling, timing of use and losses

Urea:

- Fairly rapid conversion to ammonium (days) when moisture present and in the presence of the urease enzyme in soil and plant residue
- Converts generally within days/weeks to nitrate, which can be subject to denitrification losses under certain conditions: $\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{NO} + \text{N}_2\text{O} \rightarrow \text{N}_2 (g)$; and also subject to leaching losses
- Especially under warm conditions, as urea converts through the ammonia gas phase, volatilization losses also occur – can affect seedling roots and shoots. Helps if applied urea is incorporated by irrigating soon after application, or by incorporating if broadcast applied
- For this combination of reasons, it can generally be considered better to apply urea forms closer to the timing of planting to reduce the time period for the above losses to occur
Some fertilizer N characteristics with potential to impact handling, timing of use and losses

Urea-Ammonium Nitrate (UAN) solutions (UAN-28 or 32):

- Since these solutions have both urea and nitrate in them, the same losses previously mentioned associated with predominately nitrate materials or with urea both apply.
- Injections or incorporation of sidedress applications of UAN solutions or urea should generally be done to a depth of 4 inches or more.
- UAN solution applied as a band dribbled on the soil can be a better approach than any kind of broadcast application, especially in situations with surface crop residue, since the narrower band limits residue contact and reduces volatilization losses.
Some fertilizer N characteristics with potential to impact handling, timing of use and losses

**Ammonium Nitrate or Ammonium sulfate:**
- Both are suitable for broadcast applications and have less likelihood for volatilization losses than urea-containing N fertilizers.
- Ammonium sulfate is an acidifying fertilizer, which might be an advantage or a disadvantage, depending on the soil and crop situation.
- Ammonium in these fertilizers can quickly be converted to nitrate and subject to leaching losses, so it is better to apply these materials closer to the primary time of crop uptake.
Consider N “stabilization” products as an addition to fertilizer applications?

N Stabilization Products, products that could impact volatilization and nitrification losses:

Examples of products available:

UREASE INHIBITORS

- Agrotain or Agrotain Ultra (liquid), others not all registered for use in CA - directed toward reductions in volatilization losses
- Supposed to work as a urease inhibitor to reduce urease activity, an enzyme that promotes volatilization losses
- Use with urea granular or with liquid UAN, urea, ammonium nitrate sol’ns
- In studies mostly in other states, has shown some utility under situations such as no-till, reduced till with higher residues
Consider N “stabilization” products as an addition to fertilizer applications?

N Stabilization Products, products that could impact volatilization and nitrification losses:

Examples of products available:

UREASE INHIBITOR & NITRIFICATION INHIBITOR

- Agrotain Plus (dry concentrate) – urease inhibitor plus nitrification inhibitor to try to maintain N in the ammonia form for longer

- In some studies and locations, there have been modest yield improvements in a few crops, but the primary benefit in most studies seems to be better retention of N within the active root zone

- May be worth some follow-up to determine consistency of efficacy and value relative to cost in situations more prone to nitrification losses
**Deficit SDI Irrigation Approaches** — change in irrigation systems can mean changes in N delivery

- Irrigation systems such as drip, microspray and some pivot or linear sprinkler systems offer possibilities of a higher level of control over application rates, with low dose, multiple nutrient applications possible that avoid some of the issues with large, single-shot applications
- How well these work in supplying N in adequate amounts to the plants depends on knowledge of crop uptake patterns and how growth or yield limits occur
- Irrigations can still range from deficit to excess, so possibility of control over nitrate movement depends still on how well you match water applications to crop water use and avoid deep percolation losses *(more from Dr. Schwankl)*
Nitrogen Uptake – drip irrig.
Acala cotton (yld=1430 kg/ha)
Lint Yield Responses to different timing and amounts of applied N through drip system - cotton WSREC – Acala – years #1 & 2
(Irr.Trt #3 = 100/80/80)
Soil sampling as a basis for decisions –
some considerations
Soil NO3-N quick test experiences

SOIL NITRATE QUICK TEST
(Tim Hartz, Richard Smith, others (UCCE & UC Davis)

- Experience in recent years with use in multiple vegetable crops, particularly in Salinas Valley conditions
- Some more limited experience also using it in cotton and sorghum

Approach:
- Do this test before sidedress fertilizer N application to help make decisions for vegetable crops has been with soil cores in upper 6 to 12 inches (after eliminating the upper 2-3 inches before sampling)
- Use an angled soil sampling approach to better represent active root zone, try for 10 to 20 soil cores to represent areas of the field
- Sample is then mixed if soil texture allows, or sub-sampled by pinching out representative samples prior to mixing
- Soil is mixed with CaCl2 extractant solution and shaken to disperse
- Nitrate paper test strips are used, visual indicator to match ppm NO3-N
- Reading on the test strip is corrected according to soil texture and relative soil moisture level to get approximation for ppm NO3-N in dry soil
If you are going to sample for soil N (or specifically nitrate), what other considerations are there?

Field Variability — experiences with irrigation water uniformity, problem areas of fields

- Can argue that one of the more valuable sets of knowledge producers / farm managers have is an understanding of weak areas of fields, how the fields take in irrigation water and inherent differences in factors such as infiltration rates and variability in soil water intake – big potential to also impact nutrient uptake versus movement below root zones
Sources of observed variation in soil nitrate sampling results

- Time and Depth of sampling during winter / spring
  - In semi-arid, irrigated mgmt, some benefits in using timing close to planting

- Prior crop, uniformity of crop growth, amount of fertilizer applied OR plant material incorporated

- Location with respect to head or tail end of field (in terms of surface irrigation water movement)

- Soil texture and infiltration characteristics
Is sampling upper two feet of soil enough?

- Can depend on depth in soil profile where:
  - fertilizer nitrogen is applied
  - nitrogen moves with irrigation water & rain

... these can be highly variable with soil texture, amount of fertilizer applied, soil water infiltration characteristics, prior crops and residue or manure applications

- At some sites, upper 2 feet gives good idea of amounts of available N & levels decline with greater depth

- At other sites, significant nitrate-N exists at depths beyond 2 feet & could greatly impact crop response
Site average soil nitrate-N as function of depth sampled – year 1 sites

SOIL NITRATE-N (lbs N as NO3/ac)

Depth in soil profile (cm)

LOCATION OF EXPT
Variability in soil nitrate-N within fields \textit{spring}
(upper 2 ft, pre-fertilize, 2 clay loam soils)

SOIL NO3-N (mg / kg soil dry wt in upper 2 feet)

- SOIL A: 83 to 116 lbs/A
- SOIL B: 126 to 150 lbs/A

#### Bar Chart:
- Furrow
- Bed
- Tailwater
- Head
- AVER

### Comparison:
- SOIL A: 83 to 116 lbs/A
- SOIL B: 126 to 150 lbs/A
Cotton Nitrogen Management - Acala Cotton: Example of Field Tests, Soil & Plant Tissue Testing approach for improved N management

- Bob Hutmacher (UC Shafter REC, UCD Plant Science Dept.)
- Bruce Roberts (formerly UCCE, Kings Co. – now CSU Fresno), Brian Marsh (UCCE Kern Co.)
- Bob Travis and Bill Rains (UC Davis Plant Science Dept.)
- Mark Keeley, Raul Delgado, (UCCE Shafter REC); Ron Vargas, Bill Weir, Dan Munk, Steve Wright, Doug Munier (UCCE, Madera, Merced, Fresno, Tulare and Glenn (formerly Kern) Counties); Felix Fritschi (UCD Plant Sci. Dept. – now USDA-ARS)
- CA Dept. of Food & Agriculture – FREP program
- Cotton Incorporated - CA Crop Improvement Assoc.
Components in Approach for Improvements in Nitrogen Management in Cotton

- Prior 5-year experiments confirmed that cotton crop needs about 50-60 lbs. N / bale of lint from all sources, applied plus soil available N

- **Soil nitrate tests** are available to growers and relatively inexpensive (upper 2 feet good, deeper sampling better) - 
  *Applied N rates should be adjusted for apparent available soil N (using soil NO3)*

- **Petiole nitrate** status and **yield potential estimate**?

- Consider possibility of **reduced** or **split applications** (via side-dress or water-run)
## N fertilizer recommendations based on 5-year Management studies – cotton in CA

<table>
<thead>
<tr>
<th>Soil Residual Nitrate Levels- <strong>Upper 2 feet soil</strong> - <em>Spring pre-plant or soon after</em></th>
<th>Recommendations for N fertilizer applications/year</th>
<th>Additional Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 55 lbs N as NO3-N</td>
<td>125 to 175 lbs</td>
<td>Less if low yields predicted due to late planting, field history</td>
</tr>
<tr>
<td>55 to 100 lbs N</td>
<td>100 to 125 lbs</td>
<td><strong>Possibility of deeper N in soil profile.</strong> Use plant mapping, petiole nitrate to assess yield, N status</td>
</tr>
<tr>
<td>&gt; 100 lbs N</td>
<td>75 lbs or less</td>
<td>Use mapping, petiole nitrate to assess yield potential, likely response</td>
</tr>
</tbody>
</table>
Some questions:

- Can we typically reduce N application amounts in nearly all situations?
- Is there a yield risk with reduced N applications?
Experiment Treatments – years 1-3

SINGLE APPLICATION TREATMENTS:

- **T1 = 115 lbs N / acre** (applied plus residual determined as NO3-N in upper 2 ft soil profile)
- **T2 = 170 to 180 lbs N / acre** (applied plus residual NO3-N in upper 2 ft soil profile)
  - *1st* fertilizer application made May-early June

SPLIT APPLICATION TREATMENTS:

- **T3 = 115 lbs N / acre** (as in T1, but with supplemental N (sidedress or water-run for 55-60 added lbs N / acre)
- **T4 = 170 to 180 lbs N / acre** (as in T3, but with higher initial application amount)
  - *Supplemental application with 2nd* irrigation as water-run OR dry sidedress (generally timing within 7-14 days after 1st bloom)
- **T5 = no applied supplemental N**
<table>
<thead>
<tr>
<th>Year 3</th>
<th>A-Kern</th>
<th>B-SREC</th>
<th>C-WSREC</th>
<th>D-Tulare</th>
</tr>
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<tbody>
<tr>
<td>Residual upper 2 ft for site</td>
<td>41</td>
<td>58</td>
<td>45</td>
<td>69</td>
</tr>
<tr>
<td>T1 (115)</td>
<td>74</td>
<td>57</td>
<td>70</td>
<td>46</td>
</tr>
<tr>
<td>T2 (175)</td>
<td>134</td>
<td>117</td>
<td>130</td>
<td>106</td>
</tr>
<tr>
<td>T3 (115+)</td>
<td>134</td>
<td>117</td>
<td>130</td>
<td>106</td>
</tr>
<tr>
<td>T4 (175+)</td>
<td>194</td>
<td>177</td>
<td>190</td>
<td>166</td>
</tr>
<tr>
<td>T5 (0)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
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</table>
Irrigation water N contribution / year needs to be considered

<table>
<thead>
<tr>
<th>Year</th>
<th>Kern</th>
<th>Shafter</th>
<th>Fresno</th>
<th>WestSide</th>
<th>Kern</th>
<th>Tulare</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range of total yearly N (lbs/ac) contributed with irrigation water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>19-23</td>
<td>11-13</td>
<td>16-18</td>
<td>7-9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>11-13</td>
<td>17-22</td>
<td>7-9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11-13</td>
<td>7-9</td>
<td>10-12</td>
<td>23-26</td>
<td></td>
<td></td>
</tr>
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</table>
Suggested use plant map data

also evaluated top-5 retention at FB1 and FB6

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>Bottom 5 Fruit Branch 1\textsuperscript{st} position retention (%)</th>
<th>Height:Main Stem Node# Ratio</th>
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<tbody>
<tr>
<td></td>
<td>Timing of measurement (FP1 flower)</td>
<td>Timing of measurement (FP1 flower)</td>
</tr>
<tr>
<td></td>
<td>FB1</td>
<td>FB6</td>
</tr>
<tr>
<td>LOW</td>
<td>&lt;40</td>
<td>-2</td>
</tr>
<tr>
<td>MOD.</td>
<td>40-70</td>
<td>-1</td>
</tr>
<tr>
<td>HIGH</td>
<td>&gt;70</td>
<td>0</td>
</tr>
</tbody>
</table>

More pluses (+) indicate incr. chance positive response to more applied N

More negatives (-) suggest less chance positive response to more N
most consistent data between late squaring & 4 weeks after 1st bloom

With residual soil NO3-N of >60-70 lbs N/acre, petiole NO3 data has little sensitivity with yields <1200 lbs/acre

At lower residual soil N or with yields > 1400 lbs N/acre, utility of petiole data improves

With split applications or low-rate frequent nutrient applications, lower early bloom petiole NO3-N still ok

Similar approaches needed if use sap nitrate levels, chlorophyll fluorescence or other approaches – ie under what conditions do they work
Cotton - WSREC - 67 lbs N/A in top 4 ft with yields ranging from 1590 to 2260 lbs/A

Impacts of high yields on petiole nitrate sensitivity
# Yield Responses to Supplemental N

**Trt 3 (extra N) versus Trt 1; Trt 4 (extra N) versus Trt 2**

<table>
<thead>
<tr>
<th>Year</th>
<th>Site/Year</th>
<th>Yield</th>
<th>Yield Response Supplemental N (yield increased (+) or decreased (-) in: Trt 3 vs. 1 and Trt 4 vs. 2</th>
<th>Petiole NO3 status of Trt 1 from 1st to peak bloom</th>
<th>Petiole NO3 status of Trt 2 from 1st to peak bloom</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Defic. border</td>
<td>Adeq.</td>
</tr>
<tr>
<td>2</td>
<td>A – 1780</td>
<td>1780</td>
<td>Trt 3 versus Trt 1</td>
<td>+44 NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B – 2040</td>
<td>2040</td>
<td></td>
<td>+752</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C – 2000</td>
<td>2000</td>
<td></td>
<td>+315</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>A – 1490</td>
<td>1490</td>
<td></td>
<td>+333</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B – 1560</td>
<td>1560</td>
<td></td>
<td>+42 NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C – 1770</td>
<td>1770</td>
<td></td>
<td>-101</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D – 1410</td>
<td>1410</td>
<td></td>
<td>+152</td>
<td></td>
</tr>
</tbody>
</table>
Change in Soil NO3-N (Fall minus Spring) WSREC test site – year 1

High soil water holding capacity & deep roots limit leaching potential at this site.
Soil NO3-N sat. extracts by N trt – SDI Acala
Irrig Trt 3 (100/80/80)

YEAR 1 – pre-EMERGENCE

YEAR 3 – PRE-EMERGENCE
Summary:
Approach for Improvements in Nitrogen Management in SJV Cotton

- Crop needs about 50-60 lbs. N / bale of lint from all sources, applied plus soil-available N
- In semi-arid irrigated production, soil nitrate tests available to growers are relatively inexpensive and useful (upper 2 feet good, deeper better)
- Applied N rates can be adjusted for apparent available soil N (estimate using soil NO3)
- Use plant map and petiole data to consider possible response to and utility of supplemental N applications
THANK YOU!