Atmospheric nitrogen fixation and deposition

Animal manures and biosolids

Industrial fixation (Commercial Fertilizers)

Crop harvest

Volatilization

Runoff and erosion

Denitrification

Leaching

Organic nitrogen

Ammonium ($\text{NH}_4$)

Nitrate ($\text{NO}_3$)

Plant residues

Plant uptake

Input to soil

Loss from soil

Source: http://www.ipni.net/ppiweb/ppibase.nsf/$webindex/article=C2452786852569B5005AB164B438D5E8
Loss Pathways for Nitrogen

- Ammonia Volatilization
  - Ammonia can be converted to greenhouse gases
  - Contributes to formation of particulate matter

- Nitrate Leaching
  - Groundwater pollution

- Denitrification
  - $\text{NO}_x$ gases which are greenhouse gases

- Runoff and Erosion
  - Pollution of surface waters
  - Contributes to Eutrophication (Chesapeake Bay)

- Crop harvest
  - Global NUE is 33%
  - Probably between 40-50% in US
Savings from Improving Nitrogen Use Efficiency

- Global Nitrogen Use Efficiency (NUE) = 33%*
- 1,275,516 tons N
  - N savings if NUE is increased by 1% (constant yields)
- $892,861,200 savings at $0.35/lb N

*Raun, W.R and G.V. Johnson, 1999

Fig. 2. Estimated N deposition from global total N (NOy and NHx) emissions, totaling 105 Tg N y⁻¹. The unit scale is kg N ha⁻¹ y⁻¹, modified from the original units (mg m⁻² y⁻¹).


105 Tg = 231 billion pounds N = $81 billion
Global population trends from 1860 to 2000 (billions, left axis) and reactive nitrogen (Nr) creation (teragrams nitrogen [Tg N] per year, right axis). (Galloway et al., 2003)
Common Sources of Nitrogen

- Anhydrous Ammonia (82-0-0)
- Granular Urea (46-0-0)
- Urea Ammonium Nitrate Solutions
  - 28-32% Nitrogen
- Ammonium Sulfate
- Ammonium Nitrate
- Organic N Sources
  - Poultry Litter
  - Dairy Slurry/Manure
  - Bio-solids
Liebig’s Law of the Minimum

- Yield will be limited by the amount of the most limiting nutrient!!!
Current Soil Fertility Recommendations for Cotton

✧ **Nitrogen**
  
  ✧ Current recommendations: 50 lbs N/acre per bale expected yield
    ✧ 2 bale = 100 lb N per acre uptake
    ✧ 3 bale = 150 lb N per acre uptake
  
  ✧ 20-30% applied pre- or at planting
  
  ✧ 70-80% applied in-season (1 or 2 applications??????)
  
  ✧ In-season monitoring with tissue testing

✧ **Sulfur**

  ✧ Current Recommendations: Apply 20 lbs S per acre
  
  ✧ Easy time to put that out is with side-dress N
  
  ✧ Want to use a source containing sulfate as elemental S needs time to break down and become plant available
Current Nitrogen Management in Cotton

- **Pre-plant Fertilizer**
  - 20-30% N

- **Side-dress N application**
  - 70-80% N
  - Single or Split Applications

*Graph showing cotton growth stages and nitrogen application timing.*

- **Numbers/acre (X1000)**
  - Emergence
  - Cotyledons
  - 4 True Leaves
  - 6-8 Nodes
  - Squares
  - Bolls
  - Open Bolls

- **Days After Planting**
  - May 1
  - June 1
  - July 1
  - Aug 1
  - Sept 1
  - Oct 1
Summary of N, K, and S Uptake

- Nitrogen Uptake
  - 20-30 lb N ac\(^{-1}\) between planting and 1st square
  - From 1st square to harvest cotton needed an additional 100 lb N ac\(^{-1}\)
  - 120-140 lb N ac\(^{-1}\) total uptake at defoliation
  - Substantial N can be supplied by soil ~80 lb N ac\(^{-1}\)
    - Depends on soil typed and residual N available
  - Largest sink for N at harvest was cottonseed

- Sulfur Uptake
  - 2.5 - 6 lb S ac\(^{-1}\) between planting and 1st square
    - Uptake at 1st square can be as high as 8-10 lb S ac\(^{-1}\)
  - 15 lb S ac\(^{-1}\) total uptake at cutout at normal S application rates
    - As high as 25 lb S ac\(^{-1}\)
  - 18-22 lb S ac\(^{-1}\) total uptake at defoliation
  - Majority of S uptake occurs prior to cutout and major sink were leaves

- Potassium Uptake
  - 30-35 lb K2O ac\(^{-1}\) between planting and 1st square
  - From 1st square to harvest cotton need an additional 100 lb K2O ac\(^{-1}\)
  - 120-140 lb K2O ac\(^{-1}\) total uptake at cutout
In-Season Monitoring of Nitrogen Status in Cotton
University Recommended Petiole Nitrate and Phosphorus Concentrations

Adapted from Mitchell and Baker (2009)

**“Arkansas” Interpretation (Benton and others 1979)**

<table>
<thead>
<tr>
<th>Time of sampling</th>
<th>Nitrate nitrogen (ppm)</th>
<th>Phosphorus (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week of bloom</td>
<td>10,000–35,000</td>
<td>&gt;800</td>
</tr>
<tr>
<td>Bloom + 1 week</td>
<td>9,000–30,000</td>
<td>*</td>
</tr>
<tr>
<td>Bloom + 2 weeks</td>
<td>7,000–25,000</td>
<td>*</td>
</tr>
<tr>
<td>Bloom + 3 weeks</td>
<td>5,000–20,000</td>
<td>*</td>
</tr>
<tr>
<td>Bloom + 4 weeks</td>
<td>3,000–13,000</td>
<td>*</td>
</tr>
<tr>
<td>Bloom + 5 weeks</td>
<td>2,000–8,000</td>
<td></td>
</tr>
<tr>
<td>Bloom + 6 weeks</td>
<td>1,000–5,000</td>
<td></td>
</tr>
<tr>
<td>Bloom + 7 weeks</td>
<td>0–5,000</td>
<td></td>
</tr>
<tr>
<td>Bloom + 8 weeks</td>
<td>0–5,000</td>
<td></td>
</tr>
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</table>

* A decrease in P concentration of more than 300 ppm from the previous week usually indicates moisture stress

**“Georgia” Interpretation (Lutrick and others 1986; Plank, personal communication)**

<table>
<thead>
<tr>
<th>Time of sampling</th>
<th>Nitrate nitrogen (ppm)</th>
<th>Phosphorus (ppm)</th>
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<tbody>
<tr>
<td>Week before first bloom</td>
<td>7,000–13,000</td>
<td>&gt;800</td>
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<tr>
<td>Week of bloom</td>
<td>4,500–12,500</td>
<td>&gt;800</td>
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<tr>
<td>Bloom + 1 week</td>
<td>3,500–11,000</td>
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</tr>
<tr>
<td>Bloom + 2 weeks</td>
<td>2,500–9,500</td>
<td>*</td>
</tr>
<tr>
<td>Bloom + 3 weeks</td>
<td>1,500–7,500</td>
<td>*</td>
</tr>
<tr>
<td>Bloom + 4 weeks</td>
<td>1,000–7,000</td>
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<tr>
<td>Bloom + 5 weeks</td>
<td>1,000–6,000</td>
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<tr>
<td>Bloom + 6 weeks</td>
<td>500–4,000</td>
<td></td>
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<tr>
<td>Bloom + 7 weeks</td>
<td>500–4,000</td>
<td></td>
</tr>
<tr>
<td>Bloom + 8 weeks</td>
<td>500–4,000</td>
<td></td>
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</tbody>
</table>

* A decrease in P concentration of more than 300 ppm from the previous week usually indicates moisture stress

Adapted from Mitchell and Baker (2009)
### North Carolina Sufficiency Ranges for Petiole Nitrate-N throughout the Growing Season

#### Table 4. Desired range of petiole nitrate-nitrogen (ppm) by growth stage and week

<table>
<thead>
<tr>
<th>Week</th>
<th>Seedling (S)</th>
<th>Early (E)</th>
<th>Bloom (B)</th>
<th>Fruit (F)</th>
<th>Mature (M)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>16,000–30,000</td>
<td>12,000–18,000</td>
<td>6,000–12,000</td>
<td>1,000–6,000</td>
<td>200–2,500</td>
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<tr>
<td>2</td>
<td>15,000–25,000</td>
<td>10,000–16,000</td>
<td>5,000–11,000</td>
<td>500–5,000</td>
<td>150–2,000</td>
</tr>
<tr>
<td>3</td>
<td>14,000–22,500</td>
<td>8,000–14,000</td>
<td>3,500–10,000</td>
<td>250–4,000</td>
<td>100–1,500</td>
</tr>
<tr>
<td>4</td>
<td>13,000–20,000</td>
<td>7,500–13,000</td>
<td>2,000–8,000</td>
<td>100–3,000</td>
<td>50–1,000</td>
</tr>
</tbody>
</table>

#### Table 1. Consecutive growth stage and week designations for cotton tissue samples

<table>
<thead>
<tr>
<th>S = Seedling, 4 Wks 1–4</th>
<th>E = Early Vegetative Growth, 4 Wks 1–4</th>
<th>B = Bloom, 4 Wks 1–4</th>
<th>F = Fruit, 4 Wks 1–4</th>
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</thead>
<tbody>
<tr>
<td>S1</td>
<td>S2</td>
<td>S3</td>
<td>S4</td>
</tr>
</tbody>
</table>

Adapted from Cleveland (2012)
Fertilizer Source and petiole Nitrate-N at 100 lb N acre$^{-1}$
Petiole Nitrate-N and Nitrogen Rate
Combined Nitrate-N Concentrations during Bloom in Virginia

Average Petiole Nitrate-N
7,780 ppm
### Leaf Tissue Nutrient Concentrations at TAREC from 2013-2015

<table>
<thead>
<tr>
<th>Nutrient Systems</th>
<th>Leaf Nutrient Concentrations</th>
<th>%</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Unfertilized Control</td>
<td>3.41 c*</td>
<td>0.34</td>
</tr>
<tr>
<td>Broadcast Agronomic Control</td>
<td>4.32 a</td>
<td>0.32</td>
</tr>
<tr>
<td>Liquid Starter Control</td>
<td>4.23 a</td>
<td>0.32</td>
</tr>
<tr>
<td>100% 2X2 N-P-K-S</td>
<td>4.29 a</td>
<td>0.31</td>
</tr>
<tr>
<td>100% Deep Placement N-P-K-S</td>
<td>4.16 b</td>
<td>0.31</td>
</tr>
</tbody>
</table>

*Values with the same letter are not significantly different at α = 0.05
† Week of bloom

---

### Macronutrients (%)

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
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</thead>
<tbody>
<tr>
<td>early bloom</td>
<td>3.0–4.5</td>
<td>0.2–0.65</td>
<td>1.5–3.0</td>
<td>2.0–3.5</td>
<td>0.3–0.9</td>
<td>0.25–0.8</td>
</tr>
<tr>
<td>late bloom / maturity</td>
<td>3.0–4.5</td>
<td>0.15–0.6</td>
<td>0.75–2.5</td>
<td>2.0–4.0</td>
<td>0.3–0.9</td>
<td>0.3–0.9</td>
</tr>
</tbody>
</table>

Adapted from Mitchell and Baker (2009)
Combined Leaf Nitrogen and Petiole Nitrate-N
1st Week of Bloom

Leaf N = 0.414ln(Petiole Nitrate) + 0.8599
$R^2 = 0.57$

Leaf N (%) vs. Petiole Nitrate-N (ppm) for different N rates:
- 0 lbs N per acre
- 30 lbs N
- 40 lbs N
- 60 lbs N
- 80 lbs N
- 90 lbs N
- 120 lbs N
Nitrogen Management in Cotton at TAREC
Using Tissue Testing For Nitrogen to Predict Lint Yield

- Side-dress N Rates
  - 40-60 lbs N / Ac
  - Split App. Management

- Side-dress N Rates
  - 70 - 90 lbs N / Ac
  - Single App. Management
Relative Yield, Petiole Nitrate-N, and Leaf Nitrogen during the 1st week of Bloom
In-Season Management Scenarios

1. N Management System
   ◦ Split vs Single Side-dress Application
   ◦ Recommend 50 lbs N per acre per bale of expected yield

2. How much N has been applied at side-dressing?
   ◦ 40-60 lbs N
   ◦ 70+ lbs N

3. What were the results of the petiole and leaf analysis?
   ◦ Leaf N?
     ◦ 0 - 3.75%
     ◦ 3.75 - 5.00%
   ◦ Petiole Nitrate-N?
     ◦ 0 - 4,500 ppm nitrate
     ◦ 4,500 - 8,000 ppm
     ◦ 8,000 + ppm
Making the Appropriate N Decisions

- Single Side-dress N Application System
  - 60 lbs N applied at MHS
  - Leaf N @ 1st bloom = 4.00%
  - Petiole Nitrate = 7,000 ppm
- This scenario is in the “gray area”,
  - Take into account total applied N
    - 25 lbs or less = Apply an extra 20-30 lbs addition N per acre
    - 30 lbs or more = Most likely have enough N available to achieve yield goal.
- Weather conditions and early season stress will influence tissue analysis results
- Maybe not a “Two” Prong Approach… More like a 4-5!
- The earlier in the bloom period the better correlation to yield and gives more time to correct N problems!!!
Sulfur Management in Cotton
Apply Sulfur? Why?

1989

2014

Retrieved from: http://www3.epa.gov/castnet/maps/prism/1113/so4_d-1113.png

2016 Beltwide Cotton Conferences
## Spatial Variability in Soil Testing For Sulfur

### Table

<table>
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<tr>
<th>3</th>
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</table>

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2016 Beltwide Cotton Conferences
Petiole Sulfur Concentration, Application Rate, and Variety During the 1st Week of Bloom

Location 1

Location 2

2016 Beltwide Cotton Conferences
Petiole Sulfur for Fluid N/S Formulations

- 32-0-0
- 24-0-0-3S
- 24-0-0-6S
- 24-0-0-9S

Suffolk

SHC

LEW
Petiole S concentration and Fertilizer Source

- **Suffolk SHC LEW**
- **Petiole Sulfur (ppm)**
  - 0
  - 200
  - 400
  - 600
  - 800
  - 1000
  - 1200
  - 1400
  - 1600
  - 1800

- **Urea + AMS**
- **UAN32 + ATS**

![Graph showing petiole sulfur concentration for different fertility sources](image)
Sulfur Fertilization of Virginia Cotton

\[ \text{Leaf S} = 0.0002 \times (\text{Petiole S}) + 0.47 \]

\[ R^2 = 0.39 \]
Ratio of Petiole Nitrate-N to Petiole S Concentrations

**Location 1**

- **Sulfur Application Rate (lbs S ac\(^{-1}\))**: 0, 10, 20, 30, 40
- **Petiole Nitrate-N : Petiole Sulfur**: 0, 5, 10, 15, 20, 25
- Varieties: PHY 333WRF, PHY 499WRF, ST 4946GLB2

**Location 2**

- **Sulfur Application Rate (lbs S ac\(^{-1}\))**: 0, 10, 20, 30, 40
- **Petiole Nitrate-N : Petiole Sulfur**: 0, 5, 10, 15, 20
- Varieties: PHY 333WRF, PHY 499WRF, ST 4946GLB2

Comparison of Sulfur Application Rates and their effects on the ratio of Petiole Nitrate-N to Petiole S Concentrations.
Variety and Sulfur Application Rate on Lint Yield in 2015

Location 1

[Bar chart showing the effect of sulfur application rate on lint yield for different varieties at Location 1.]

Location 2

[Bar chart showing the effect of sulfur application rate on lint yield for different varieties at Location 2.]
Variety and Sulfur Application Rate on Lint Yield in 2016
Nitrogen and Sulfur Interactions in Cotton...
Petiole Nitrate-N and Sulfur Rate During The 1\textsuperscript{st} Week of Bloom
Lint yield and N/S Source
Suffolk, vA

Urea + AMS
Lint Yield = 1208 + 5.66*SRate - 0.11*(Srate)^2
R^2 = 0.99

UAN32 + ATS
Lint Yield = 1115 + 14*SRate - 0.39*(Srate)^2
R^2 = 0.99

Sulfur application rate (lb. S ac^-1)

Lint Yield (lb. ac^-1)
0
200
400
600
800
1000
1200
1400
Lint yield and N/S Source

Southampton, VA

Lewiston, NC
Fluid N/S Formulations and Lint Yield
Nitrogen and sulfur Rates explaining Lint Yield at Tarec
Leaf and Petiole N:S and Lint Yield at TAREC
Summary

- High nitrogen application rates increased yields at high yielding locations and was detrimental to lint yields at low yielding sites.
  - When high N rates and high S rates were applied together excess growth made defoliation difficult.
  - N rates between 80 -120 lb N per acre optimized lint yields at responsive sites
  - Critical petiole nitrate-N level of 4,500 ppm nitrate-N
- Petiole nitrate-N, petiole sulfur, leaf nitrogen, and leaf sulfur concentrations increased with increasing application rates.
- No current sufficiency range is documented for petiole sulfur concentrations
- Leaf Sulfur concentrations were above current critical levels of 0.25% during the first week of bloom even when no S was applied.
- 20 lb. S ac⁻¹ maximized yield at the high yielding responsive site.
- At all locations 24-0-03S increased lint yields above 32-0-0 when averaged over nitrogen rates.
- Petiole Nitrate:S ratio was optimum between 10-20 and Leaf N:S was optimum at 8 at TAREC
- Differences in N/S source and application method
- Interactions between N and S in petiole nitrate-N and lint yield.