Suites of 4R N Management Practices for Improved Production and Environmental Outcomes

Clifford S. Snyder, PhD, CCA
Nitrogen Program Director
International Plant Nutrition Institute
Conway, Arkansas, USA 72034

Presentation to InfoAg
St. Louis, MO,
August 2-4, 2016
• The dynamic challenges of achieving increased crop yields, reduced losses of nitrogen (N) to the environment, and improved profitablity can be daunting to crop producers (and their advisers).

• The public is demanding reduced agricultural nutrient impact on:
  – water resources: surface and groundwater
  – air quality: including lower greenhouse gas (especially nitrous oxide, N$_2$O) and ammonia emissions.

• Better soil management and soil health are also being advocated by NRCS, environmental NGOs, sustainability organizations, & others;
  – including better indicators of desirable soil biological, chemical, and physical characteristics.
Corn Acreage, Fertilizer Use, & Spring Nutrient Discharge in the Mississippi River Basin: Relationships & Impact on Hypoxia

C.S. Snyder, PhD, CCA
Nitrogen Program Director
ASA/SSSA Meetings 2009

Nitrogen Partial Balance, Use Efficiency by Corn, and Flux From the Mississippi River Basin to the Gulf of Mexico: An Update

C.S. Snyder¹, P.E. Fixen², R. Williams³, Q. Rund³, and T.S. Murrell⁴
¹ IPNI Nitrogen Program Director, Conway, AR, ² IPNI Sr. V.P., Americas and Oceania Group and Director of Research-Brookings, SD, ³ PAQ Interactive - Monticello, IL, and ⁴ IPNI Northcentral Director-West Lafayette, IN
SSSA Meetings 2012

Spring Nutrient Flux to the Gulf of Mexico and Nutrient Balance in the Mississippi River Basin

C.S. Snyder, PhD, CCA
Nitrogen Program Director, Conway, AR

T. Scott Murrell, PhD
Director, North American Program
West Lafayette, IN

Nitrogen and Phosphorus Consumption and Balance in the Mississippi River Basin: 1987 to 2012

C.S. Snyder, PhD, CCA
Nitrogen Program Director, IPNI Conway, AR

T. Scott Murrell, PhD
Director, North America, IPNI West Lafayette, IN

P.E. Fixen, PhD
Senior VP., Americas and Oceania Group, and Director of Research, IPNI Brookings, SD

T. Scott Murrell, PhD
Director, North America, IPNI West Lafayette, IN

Q. Rund and R. Williams
PAQ Interactive Monticello, IL

SWCS Meetings
Louisville, KY August 24-28, 2016
www.ipni.net
4Rs for Healthy Soils & Healthy Waters

C.S. Snyder, PhD, CCA
Nitrogen Program Director, Conway, AR

Healthy Soils and Healthy Waters Workshop
Columbus, OH September 15-16, 2014
www.ipni.net
Improved N Management to Help Achieve Reduced N\textsubscript{2}O Emissions and Minimize Other N Losses

Clifford S. Snyder, PhD, CCA
Nitrogen Program Director
International Plant Nutrition Institute
Conway, Arkansas, USA 72034

Presentation to Coalition on Agricultural Greenhouse Gases (C-AGG)
Denver, CO, July 12, 2016
Right means Sustainable

- Right source, rate, time, and place
- Outcomes valued by stakeholders

“There is an immediate connection between applying the right nutrient source, at the right rate, right timing, and right placement, and beneficial impacts on components of the natural capital evidenced through better crop performance, improved soil health, decreased environmental pollution, and the protection of wildlife. “ (4R Plant Nutrition Manual pg. 1-2)
N Use Efficiency & Effectiveness - Affected by:

- N supply from:
  - Soil
  - Fertilizer
  - Other inputs

- Balanced supply of other essential nutrients

- Plant uptake (physiology, transfer)

- N losses
  - volatilization, leaching, runoff, **denitrification** (and nitrification)

- All are affected by cropping system management and environmental conditions
Nutrient Use Efficiency and Effectiveness in North America: Indices of Agronomic and Environmental Benefit

By C.S. Snyder and T.W. Bruulsema, International Plant Nutrition Institute

MINERAL FERTILIZERS have made it possible to sustain the world’s growing population, sparing millions of acres of natural and ecologically-sensitive systems that otherwise would have been converted to agriculture. Today, economic and environmental challenges are driving increased interest in nutrient use efficiency. Higher prices for both crops and fertilizers have heightened interest in efficiency-improving technologies and practices that also improve productivity. In addition, nutrient losses have been reduced by improving use efficiencies of nutrient phosphorus (P).

The world’s population, growing in both number and by consuming more food, feed, fiber, and fuel—increments. Since fertilizers are made from non-renewable resources, use efficiencies will continue. At the same time, use effectiveness for improved productivity and environmental sustainability is necessary.

System Efficiency

Efficiencies are generally calculated as ratios of outputs to inputs in a system. The “system” can be defined in many ways, depending on the interest of the observer.

Agricultural cropping systems contain complex combinations of components, including: soils, soil microbes, roots, plants, and crop rotations. Improvements in the efficiency of one component may or may not be effective in improving the efficiency of the cropping system. Efficiency gains in the short term may sometimes be at the expense of those in the long term. Short-term reductions in application rates increase nutrient use efficiencies, even when yields decline. However, in the long term, lower yields reduce production of crop residues, leading to increased erosion risks, decreased soil organic matter, and diminished soil productivity. Sustainable system efficiency demands attention to the long-term impacts.

Best management practices (BMP) focus on the effectiveness of fertilizers and keeping them in the field for use by the intended crop. In adapting cropping systems to the economic and environmental challenges noted above, effectiveness is maximized when the most appropriate nutrient sources are applied at the right rate, time, and place in combination with conservation practices such as buffer strips, continuous no-till, cover crops, and riparian buffers within intensively managed cropping systems that achieve both increasing yields and diminishing nutrient losses. This approach ensures that improvements in the nutrient use efficiency of the components contribute toward improving the efficiency of the entire system.

Figure 1. Corn grain produced in the U.S. per unit of N applied (PFP), 1964 to 2006.

Snyder and Bruulsema 2007
<table>
<thead>
<tr>
<th>NUE Term</th>
<th>Calculation</th>
<th>Reported Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PFP</strong> - Partial factor productivity</td>
<td>$Y/F$</td>
<td>40 to 80 units of cereal grain per unit of N</td>
</tr>
<tr>
<td><strong>AE</strong> - Agronomic Efficiency</td>
<td>$(Y-Y_0)/F$</td>
<td>10 to 30 units of cereal grain per unit of N</td>
</tr>
</tbody>
</table>
| **PNB** - Partial nutrient balance (removal to use ratio) | $U_H/F$             | 0 to > 1.0 - depends on native soil fertility and fertility maintenance objectives  
<1 in nutrient deficient systems (fertility improvement)  
>1 in nutrient surplus systems (under replacement) 
Slightly less than 1 to 1 (system sustainability) |
| **RE** – Recovery efficiency of applied nutrient | $(U-U_0)/F$         | 0.1 to 0.3 - proportion of P input recovered first year  
0.5 to 0.9 - proportion of P input recovered by crops in long-term cropping systems  
0.3 to 0.5 - N recovery in cereals-typical  
0.5 to 0.8 - N recovery in cereals- best management |

F-amt. nutrient applied, Y- yield of harvested portion with applied nutrient, $Y_0$- yield of harvested portion with no applied nutrient, $U_H$—nutrient content of harvested portion of crop, $U$ —total nutrient uptake in aboveground biomass with nutrient applied, $U_0$ —total nutrient uptake in aboveground biomass with no nutrient applied
Fertilizer Nitrogen BMPs to Limit Losses that Contribute to Global Warming

By C.S. Snyder

FERTILIZER BMPs are important tools for improving crop yields, reducing nutrient losses, and minimizing environmental impacts. Properly balanced plant nutrition with fertilizer BMPs will minimize the application of nitrogen (N) in crop yields, crop quality, profitability, and nutrient losses to water or air is greatly influenced by other agronomic practices such as plant population, cultivars, tillage, and pest management, as well as conservation practices such as terraces, strip cropping, windbreak management, riparian buffers, shelter belts, and others (Olsen et al., 2007). Practices that are defined enough to be making on-farm fertilizer use decisions can be “best” practices only when used in conjunction with other appropriate agronomic and conservation BMPs. A best fertilizer practice can be totally ineffective if the cropping system is which it is used has other serious inadequacies (Olsen et al., 2007).

The discussion and guides that follow are oriented toward the central U.S. Corn Belt, but are relevant to other cropping systems with similar crop geographies. They are provided to assist in fertilizer nitrogen (N) management decisions that will help lessen the impact of fertilizer N use on greenhouse gas (GHG) emissions and help mitigate the global warming potential (GWP) – expressed as CO₂ equivalent. The three GHGs of interest to agriculture are nitrous oxide (N₂O), methane (CH₄), and CO₂. The GWP of CH₄ is 23 times greater and the GWP of N₂O is 296 times greater than that of CO₂. Because fertilizer nitrogen use may be associated with N₂O emissions, and because the GWP of N₂O is much greater than CO₂, fertilizer N BMPs to reduce N₂O emissions are emphasized in this practical guide. For example, fertilizer N BMPs which help minimize excess nitrate (NO₃⁻) in the soil during warm, wet, or waterlogged conditions can result in lowered rates for NO₃⁻ emission (Snyder et al., 2007).

Table 1. Relative effectiveness of management scenarios, shown as advantage of “Scenario 1” over “Scenario 2,” in reducing N losses and greenhouse gas emissions. Effectiveness rating represents estimate of the relative potential N loss reduction, on-farm and within watershed.

- **Right agronomic N rate**
  - **Scenario 1**
    - All Sources: Accounting for soil N supply and input sources (e.g., manure, irrigation water, etc.)
    - All Sources: Site-specific N management (variable rate and/or source)
  - **Scenario 2**
    - No such N accounting (assumes over-application)
    - No site-specific management

- **Right N timing**
  - **Scenario 1**
    - AA: Applied in the fall after soil temp below 50°F (10°C) for spring-planted crops
    - AA, AS, PA, U, UAN, AN, PN: Spring application, for spring planted crops
    - AA, AS, PA, U, UAN, AN, PN: Spring split or sidedress applied, for spring planted crops
    - AA, AS, PA, U, UAN, AN, PN: Spring or split-fall spring application, for fall planted crops (e.g., wheat, canola)
    - AA, AS, PA, U, UAN, AN, PN: Nitrogenation inhibitor used
    - U: Controlled release technology used
  - **Scenario 2**
    - No waiting
    - Fall application
    - All preplant applied
    - All fall applied
    - None used
    - None used

- **Right N placement**
  - **Scenario 1**
    - AS, PA, U, UAN, AN, PN: Subsurface incorporation
    - U, UAN: Surface broadcast
    - AS, PA, U, UAN, AN, PN: Shallow sidedress band – 1 in. (2 cm)
    - U, UAN: Surface applied with urease inhibitor; abundant crop residues
    - U, UAN: Surface applied with urease inhibitor; minimal crop residues
  - **Scenario 2**
    - Surface broadcast
    - Sidedress band deeper than necessary – ≥ 4 in. (10 cm)
    - No inhibitor
    - No inhibitor

**Legend for ratings in table:**

- -75
- -50
- 0
- 50
- 100
- Rating scale: 100 to 0 (e.g., negative to positive), or a single value.

**Notes:**

1. Relative percentage (%) advantage of “Scenario 1” over “Scenario 2,” estimated from available literature and experienced observation. This rating scheme does not identify the quantity of N loss, which can be relatively small e.g., 1 to 2 lb/acre (1 to 2 kg/ha) in some conditions. Relative effects do not include emissions associated with manufacture or transport of inputs. Ratings are subject to change with research progress.

2. N sources: AA = anhydrous ammonia, AS = ammonium sulfate, PA = predominiately ammonium containing, U = urea, UAN = urea ammonium nitrate solutions, AN = ammonium nitrate, PN = predominiately nitrate containing.

3. Data insufficient to allow ratings for emissions of the other two principal greenhouse gases, CH₄ and CO₂.

Better Crops
Vol. 90, No. 2 . 2006

- 6 BMP articles on different crop systems in different U.S. regions
Nutrient Performance Indicators:
The importance of farm scale assessments, linked to soil fertility, productivity, environmental impact and the adoption of grower best management practices.

- **Which practice for best results?**
- For increased profitability
- For reduced ammonia emissions
- For reduced nitrate runoff/leaching/drainage
- For reduced nitrous oxide GHG emissions
- For system sustainability and resiliency
Agriculture: sustainable crop and animal production to help mitigate nitrous oxide emissions
CS Snyder¹, EA Davidson², P Smith³ and RT Venterea⁴
## Recent Examples of N Management Changes on N$_2$O Emission Reduction (1 of 4)

<table>
<thead>
<tr>
<th>Comparison technology or N practice</th>
<th>Reference technology or fertilizer N practice</th>
<th>Emission reduction (%)</th>
<th>Comment [COSUST paper reference]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea with urease inhibitor (UI)</td>
<td>Urea alone</td>
<td>Nil</td>
<td></td>
</tr>
<tr>
<td>Nitrification inhibitor (NI) or polymer coated urea (PCU)</td>
<td>Conventional N, no inhibitor or polymer coating</td>
<td>35-38</td>
<td>Meta analysis; 35 studies [36]</td>
</tr>
<tr>
<td>Urea</td>
<td>Anhydrous ammonia</td>
<td>50</td>
<td>15-yr.-old corn-soybean system [33]</td>
</tr>
<tr>
<td>Change in time, source, place</td>
<td>Standard or reference N management</td>
<td>20-80</td>
<td>Summary of &gt;20 studies [37]</td>
</tr>
<tr>
<td>Urea ammonium nitrate (UAN) with NI</td>
<td>UAN with no inhibitor</td>
<td>19-67</td>
<td>Side-dressed UAN, subsurface colter-applied at V4-V6 [41]</td>
</tr>
</tbody>
</table>

1 range of agricultural crops  
2 corn (maize)

## Recent Examples of N Management Changes on N$_2$O Emission Reduction (2 of 4)

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer N with UI and NI</td>
<td>Fertilizer N with no inhibitor</td>
<td>38</td>
<td>Meta analysis; 3 studies, 20 observations [42] $^2$</td>
</tr>
<tr>
<td>Fertilizer placement &gt;5cm deep</td>
<td>Fertilizer placement &lt;5 cm deep</td>
<td>&gt;30</td>
<td>Meta analysis; reduced tillage [26] $^3$</td>
</tr>
<tr>
<td>Urea with NI</td>
<td>Urea with no inhibitor</td>
<td>81-100</td>
<td>Full growing season measurements (217–382 days); fertilizer banded &gt;5 cm deep, 20 cm from plant row; clay loam soil. PSCU emissions lower than urea, first 20 days after application [43] $^4$</td>
</tr>
<tr>
<td>Polymer sulfur coated urea (PSCU)</td>
<td>Urea with no coating</td>
<td>-35 to -46</td>
<td></td>
</tr>
</tbody>
</table>

$^2$ corn (maize)  
$^3$ range of agricultural crops, excluding rice  
$^4$ sugarcane, residue removed or burned

Recent Examples of N Management Changes on N\textsubscript{2}O Emission Reduction (3 of 4)

<table>
<thead>
<tr>
<th>Comparison technology or N practice</th>
<th>Reference technology or fertilizer N practice</th>
<th>Emission reduction (%)</th>
<th>Comment [COSUST paper reference]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer N (including urea with UI and NI, urea–ammonium nitrate (UAN) with UI and NI, urea, UAN, ammonium nitrate, or PCU)</td>
<td>Poultry litter</td>
<td>46-81</td>
<td>Humid region; surface broadcast, not incorporated [39] \textsuperscript{2}</td>
</tr>
<tr>
<td>Commercial fertilizer</td>
<td>Manure</td>
<td>40</td>
<td>Meta analysis; 9 studies, 73 observations [42] \textsuperscript{2}</td>
</tr>
<tr>
<td>Calcium ammonium nitrate</td>
<td>Manure (poultry, or liquid swine, or liquid dairy)</td>
<td>54</td>
<td>Surface applied N, incorporated by tillage, day of application [40] \textsuperscript{2}</td>
</tr>
</tbody>
</table>

\textsuperscript{2} corn (maize)

## Recent Examples of N Management Changes on N$_2$O Emission Reduction (4 of 4)

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<tr>
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<tbody>
<tr>
<td>UAN with UI and NI</td>
<td>UAN with no inhibitor</td>
<td>41</td>
<td>Full growing season N$_2$O measurements; irrigated; no-till and tilled; surface banded N near emerged corn row [35] $^2$</td>
</tr>
<tr>
<td></td>
<td>Urea with no inhibitor</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>UAN with methylene urea &amp; urea triazone</td>
<td>UAN</td>
<td>28</td>
<td></td>
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<tr>
<td></td>
<td>Urea</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>PCU PCU</td>
<td>UAN</td>
<td>14</td>
<td>Dairy cows excluded 2 months prior; plant N recovery: 50 to 85% [38] $^5$</td>
</tr>
<tr>
<td></td>
<td>Urea</td>
<td>42</td>
<td></td>
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<tr>
<td>Urea with UI and NI</td>
<td>Urea with no inhibitor</td>
<td>37</td>
<td></td>
</tr>
</tbody>
</table>

$^2$ corn (maize)  
$^5$ using perennial ryegrass (*Lolium perenne* L.)/white clover (*Trifolium repens* L.) pasture

Using nitrification inhibitors to mitigate agricultural N₂O emission: a double-edged sword?

SHU KEE LAM, HELEN SUTER, ARVIN R. MOSIER and DELI CHEN
Crop and Soil Science Section, Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Parkville, VIC 3010, Australia

“… the overall impact of nitrification inhibitors ranged from -4.5 (reduction) to +0.5 (increase) kg N₂O-N/ha”

“…. the beneficial effect of nitrification inhibitors in decreasing direct N₂O emission can be undermined or even outweighed by an increase in NH₃ volatilization (that affects indirect N₂O emission)”
The Nitrogen Cycle
Few Studies Have Measured Long-Term Mass Balance: Uptake, Removal, Retention, Loss of N

Trying to quantify and predict relatively small amounts of $N_2O-N$ is quite difficult.

< one one-thousandth (0.001) of the soil organic N pool

---

**Annual N cycle for 0 to 50 cm (20 inches) of soil and continuous winter wheat for 1990-1997 on the Broadbalk Continuous Winter Wheat Experiment Plot 08 receiving 144 kilograms of N per hectare (129 lbs N/A) annually. Values include estimates of nonfertilizer N inputs (I), total N losses (L), and soil N cycling (S) derived from isotopically labeled N studies. The units for values within boxes are kg of N per hectare and units for all other values are kilograms of N per hectare per year. Uncertainties are approximately ± 5 to 10 % of the values shown. (Source: Meisinger et al, 2008)**
Field to Market - The Alliance for Sustainable Agriculture: 40 members in 2009 to >100 in 2016
Field to Market Fieldprint Calculator N₂O-N Emission Estimation Currently:

- relies on a simple nitrogen (N)-rate dependent multiplier to estimate N₂O-N emissions
  - with some broad consideration of nitrification inhibitors.
- 0.014 x N rate for direct plus indirect emissions
  - Based on IPCC approach for inventory purposes
    - 0.01 x N rate for direct N₂O-N emissions
    - 0.0035 rounded to 0.004 for indirect N₂O-N emissions
- does not consider complete 4R nutrient management
  (applying the right nutrient source at the right rate, the right time and in the right place)
Position:
Field to Market FPC N$_2$O estimator should be consistent, as much as practical, with the most current USDA published science on “baseline” emissions.
USDA NRCS Major Land Resource Regions

http://apps.cei.psu.edu/mlra/
Cooperation by USDA Office of the Chief Economist

• **Eve et al. (2014) report** - Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. Technical Bulletin Number 1939
  • “Base emission rates are estimated for each dominant crop and three soil texture classes (coarse, medium, fine) within a climatic region using process-based simulation modeling. The factors are developed at the scale of USDA Land Resource Regions (LRR).”

• **Marci Baranski** – Climate Change Specialist
  – Shared (upon request), the modeling output file that supported estimation of baseline N₂O emissions by LRR, soil texture, by crop, and by USDA ARMS surveyed (2010) N rate
  – >394,000 lines of model output data
Our Premise …… or Position
More in the Crop = Less in the Environment

• Agronomically appropriate N rates are a fundamental part of the 4Rs
Many Factors Affect N$_2$O Emission: Manageable and Unmanageable

<table>
<thead>
<tr>
<th>Management Practices</th>
<th>Environmental Factors</th>
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<tr>
<td>Fertilizer type</td>
<td>SOURCE</td>
</tr>
<tr>
<td>Application rate</td>
<td>RATE</td>
</tr>
<tr>
<td>Application technique</td>
<td>PLACE</td>
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<tr>
<td>Timing of application</td>
<td>TIME</td>
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<td>Tillage practices</td>
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<tr>
<td>Use of other chemicals</td>
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<td>Crop type</td>
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<td>Irrigation</td>
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<td>Residual N and C from crops and fertilizer</td>
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<td>Fertilizer type</td>
<td>Temperature</td>
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<tr>
<td>Application rate</td>
<td>Precipitation</td>
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<tr>
<td>Application technique</td>
<td>Soil moisture content</td>
</tr>
<tr>
<td>Timing of application</td>
<td>Organic C content</td>
</tr>
<tr>
<td>Tillage practices</td>
<td>Oxygen availability</td>
</tr>
<tr>
<td>Use of other chemicals</td>
<td>Porosity</td>
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<tr>
<td>Crop type</td>
<td>pH</td>
</tr>
<tr>
<td>Irrigation</td>
<td>Freeze and thaw cycle</td>
</tr>
<tr>
<td>Residual N and C from crops and fertilizer</td>
<td>Microorganisms</td>
</tr>
</tbody>
</table>

N$_2$O Emissions vs. N Use Efficiency

- Cropping system NUE (*i.e. apparent N recovery*)
  - improvements at modest fertilizer N rates correlated strongly with reduced yield-scaled N$_2$O emissions (from meta analyses of 19 studies, 147 observations; van Groenigen et al., 2010)

\[ r^2 = 0.99 \]

Each point: average of 3 studies, 27 observations each

Invited Scientists Who Participated in IPNI-TFI-FC March 2015 Nitrogen (N) Management Workshop

N Agronomists
- Peter Scharf – U of MO
- Dave Franzen – ND State U
- Jim Camberato – Purdue U
- Dave Mengel – KS State U
- Carrie Laboski – U of WI
- Cameron Pittelkow – U of IL
- Trent Roberts – U of AR

N₂O Scientists
- Rick Engel – Montana State U.
- Rod Venterea – MN, USDA-ARS
- Tony Vyn – Purdue U
- Jerry Hatfield – IA, USDA-ARS
- Tim Parkin – IA, USDA ARS
- Keith Paustian / Steve Ogle – CO State U.
- Steve Del Grosso – CO, USDA ARS
- Adam Chambers – OR, USDA NRCS

Canadian Scientists
- Claudia Wagner-Riddle - U of Guelph
- Mario Tenuta, U of MB
- David Burton, Dalhousie U (formerly Nova Scotia Ag. College)
- Miles Dyck, U of Alberta
7 Corn, Soybean, Wheat Regional 3-Tiered 4R-N Management Frameworks

- Irrigated corn-soybean South
- Irrigated corn-soybean North
- Non-irrigated corn-soybean west
- Non-irrigated corn-soybean east
- Non-irrigated corn-soybean N. central upper Midwest (between east, west, and northern)
- Wheat – northern Great Plains
- Wheat – southern Great Plains

- Reviewed and modified in science breakouts; presented to March 2015 Workshop invited N scientists …. using a live “blind” voting process.
- **FRAMEWORKS (with Basic, Intermediate, and Advanced/Emerging N management for improved crop N recovery (i.e. NUE) ) …… UNANIMOUSLY APPROVED**
3-Tiers of N Management

• **Below Basic BMPs** (best management practices)
  – 25% of the growers

• **Basic**
  – practices adopted by approximately 50%

• **4R Intermediate**
  – practices adopted by approximately 20%

• **4R Advanced** (or “Emerging”)
  – practices adopted by approximately 5%
<table>
<thead>
<tr>
<th>Performance Level</th>
<th>Right Source</th>
<th>Right Rate</th>
<th>Right Time</th>
<th>Right Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic</td>
<td>• Guaranteed or book value for all sources applied Urea, UAN, Anhydrous Ammonia, Manure</td>
<td>• Rate based on evidence recognized by regional soil fertility extension Properly accounting for legume &amp; Manure N</td>
<td>• Spring; not on frozen soil • Apply manure according to a manure management plan</td>
<td>• Broadcast and incorporated, injected or subsurface band • If broadcasted Urea accompanied by an inhibitor • UAN w/herbicide no more than 40 Lbs</td>
</tr>
<tr>
<td>Intermediate</td>
<td>• Guaranteed or known analysis for all sources applied; with nitrification inhibitor or controlled release if preplant; with urease inhibitor for urea/UAN surface applied sidedress</td>
<td>• Rate based on evidence recognized by regional soil fertility extension, including results of local adaptive management research. • Manure analysis required to determine rate</td>
<td>• Some or all applied nitrogen in season or if pre-plant used with nitrification inhibitor (NI) or polymer-coated</td>
<td>• Broadcast and incorporated, injected or subsurface band, surface application allowed only for sidedress urea with UI or dribbled UAN</td>
</tr>
<tr>
<td>Advanced/Emerging</td>
<td>• Guaranteed or known analysis; with nitrification inhibitor or controlled release if preplant; with urease inhibitor for urea/UAN sidedress</td>
<td>• Rate based on evidence recognized by regional soil fertility extension, or results of local adaptive management research, AND, in addition, addressing within-field and weather-specific variability using tools such as crop sensors, PSNT, models that allow adjustment of in-season N rates</td>
<td>• Some or all N applied in-season</td>
<td>• Broadcast and incorporated, injected or subsurface band, surface application allowed only for sidedress urea with UI or dribbled UAN</td>
</tr>
</tbody>
</table>
Excel sheets enabling 4R N management sensitivity in FPC GHG module, N$_2$O estimator

Unanimous science approval 3-Tiered 4R N Management Frameworks (Basic, Intermediate, Advanced) Improved NUE

Suites of practices: resulting in improved NUE; and ranges of expected reduced N$_2$O emissions

N$_2$O emissions vs. NUE relationships: explored in new data synthesis 4R research project (Purdue U. and USDA ARS)

N$_2$O emissions reduction factors by crop/region, aligned with USDA Land Resource Region baselines

Field to Market Pres., S & R Dir. Fall 2014 to current

IPNI, TFI, CFI Fall 2014 to current

Prasino Group Nov. 2014 to current

Science Advisory Group 12/2014 to current

SAG Mtg. and 03/2015 Workshop

• n = 338 treatment means
  – where corn whole-plant N uptake at maturity (published and unpublished)
    • 179 data points: six (6) rainfed states or provinces, and
    • 159 observations originated from three irrigated corn systems in Colorado, Minnesota and Nebraska
A fairly strong \( r^2 = 0.30 \) and linear positive relationship existed between N rate and cumulative area-scaled \( \text{N}_2\text{O}-\text{N} \) \( (\text{N}_2\text{O}-\text{N}_{(AS)} = 0.007x + 0.46) \) – However, the quantity of \( \text{N}_2\text{O}-\text{N} \) emitted per unit N rate varies substantially but is consistently lower for the relatively drier Colorado than for more humid environments in Midwestern USA and eastern Canada.

Contrary to expectation, relationships between growing season \( \text{N}_2\text{O}-\text{N} \) and both NU and NRE were generally weak (NU: \( r^2 = 0.16 \); NRE: \( r^2 = 0.01 \)) and positive linear when averaged over treatments.
• A strong and consistently positive linear relationship existed between N$_2$O and net nitrogen balance (NB), regardless of location.

• Across N rates, sources, and timings compared, … the multiple linear regression models indicated that N$_2$O$_{(AS)}$ response to N management systems was more related to NB than to any other plant N factor evaluated.
Methods – basic model used in NuGIS

A simple partial nutrient balance algorithm

1987 to 2007 in 5-yr increments set by Census of Agriculture (COA)

Not considered:
- Atmospheric deposition
- Nutrients in irrigation water
- Biosolids application
- Soil erosion
- Gaseous N emissions or leaching
Suggested to Field to Market for FPC

- Implement USDA LRR, crop, soil texture, N rate \( N_2O-N \) “baselines”

- Adjust from baseline N rate (up or down);
  - proportionalize from farmer-applied N rate to USDA ARMS 2010 survey “baseline” N rate

- Reduce that proportionalized estimate (for direct plus indirect \( N_2O-N \) emissions), using the seven corn, soybean, wheat 3-tiered 4R N management suites
  - 4R “Intermediate” suite: 7% lower
  - 4R “Advanced” suite: 14% lower
4R N Management Benefits- Science Supported

• 4R helps to protect and increase crop yields while lowering net crop-soil N balance and reducing N$_2$O-N emissions; is strongly supported by newly-published work.

• Venterea et al. (2016) - *Evaluation of Intensive “4R” Strategies for Decreasing Nitrous Oxide Emissions and Nitrogen Surplus in Rainfed Corn*
  
  – combined N management (time, source, rate), that would represent **Advanced/Emerging** suites of practices (*personal communication with R.T. Venterea, May 2016*)

• **Resulted in net N balance reductions >20 kg of N/ha and N$_2$O-N emission reductions >20 to 50%.”**

Suites of 4R Nitrogen Management Practices for Sustainable Production and Environmental Protection

4R N management frameworks to support decisions to simultaneously provide sustained and increased:

- crop yields
- farmer profitability
- soil fertility and system productivity (e.g. soil organic matter and soil organic N)
- reductions in losses of N to the environment via
  - ammonia volatilization
  - leaching/drainage/runoff losses of nitrate-N
  - gaseous emissions of nitrous oxide (N$_2$O) and di-nitrogen (N$_2$) from wet or waterlogged/saturated soil
Improving Cropping System Management Helps Improve Water Quality


- “We believe that relatively constant N fertilization rates combined with steadily increasing corn yields have improved N use efficiency and likely contributed to the nitrate-N concentration declining in the Illinois River.”

http://nitrogen.ipni.net/article/NNN-5026

U.S. Yield Trends of Major Cereal Grains

Source: USDA NASS data
SUMMARY

• Suites of 4R nutrient management practices - in the context of the entire cropping system - can help raise crop N recovery, limit environmental N losses, and foster sustainability.

• The suites of practices should be as site-specific as reasonable, based on local research: at least
  – USDA NRCS Land Resource Region specific, and sensitive to soil characteristics and climate/weather
  – Cropping system specific

• Professionals with precision agriculture tools and information management expertise can be at the center of improved 4R N management implementation, and assist farmers in addressing these shared challenges.
4R Research Fund and 4R Nutrient Stewardship

Thank You!

http://www.nutrientstewardship.com/
http://www.nutrientstewardship.com/partners