Building Risk into N Recommendations for Corn: Understanding Insurance Applications

Harold van Es
Nitrogen Concerns in Corn Production Systems

Agronomic/Economic
- ~ $5 billion/yr of N fertilizer applied to corn; large input costs for farmer
- N use efficiency low (30-70%)
- High uncertainty, and sensitivity to climate change

Environmental
- Largest energy input into cropping system
- Greenhouse gas emissions (esp. N$_2$O)
- High groundwater nitrate levels
- Hypoxia/anoxia in estuaries
Water Quality Concerns Not Improving

From: Dubrovsky et al., 2010, based on NAWQA data:

“Despite major Federal, State and local efforts and expenditures to control sources and movement of nutrients within our Nation’s watersheds, national-scale progress was not evident in this assessment”

<table>
<thead>
<tr>
<th>Site</th>
<th>Annual Mean Flow-Normalized Concentration in 1980, mg/L</th>
<th>Flow-Normalized Concentration of Nitrate as N, mg/L</th>
<th>Change, 1980–2008, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSSP-CL</td>
<td>1.13</td>
<td>0.86</td>
<td>76</td>
</tr>
<tr>
<td>IOWA-WAP</td>
<td>5.02</td>
<td>0.17</td>
<td>3</td>
</tr>
<tr>
<td>ILLI-VC</td>
<td>3.81</td>
<td>−0.04</td>
<td>−1</td>
</tr>
<tr>
<td>MSSP-GR</td>
<td>2.56</td>
<td>0.49</td>
<td>19</td>
</tr>
<tr>
<td>MIZZ-HE</td>
<td>0.96</td>
<td>0.72</td>
<td>75</td>
</tr>
<tr>
<td>MSSP-TH</td>
<td>1.93</td>
<td>0.38</td>
<td>20</td>
</tr>
<tr>
<td>OHIO-GRCH</td>
<td>0.99</td>
<td>0.03</td>
<td>3</td>
</tr>
<tr>
<td>MSSP-OUT</td>
<td>1.25</td>
<td>0.13</td>
<td>10</td>
</tr>
</tbody>
</table>

Net Change in MRB Flow-Normalized Nitrate Concentration and Flux between 1980 and 2008 (Sprague et al., 2011)
Hypoxia Zones in USA

A. Estuaries with low dissolved oxygen

B. Bottom oxygen values, in milligrams per liter

Area of Gulf Dead Zone (NOAA, 2012)

Riverine N Yield in the MRB

Nitrogen application to US agricultural lands in 2008 had a greater global warming impact than the entire US aviation industry (EPA, 2010)
Nitrous Oxide Losses Increase Exponentially With N Rate Beyond a “Critical” Value

Hoben et al., 2010.

Snyder et al., 2009, based on data by Bouwman et al., 2002

A common perception is that farmers over-apply N fertilizer, and it has been suggested that they can reduce N rates by 30-50 lbs/ac
Corn N Response and Agronomic Optimum N Rate

Yield (bu/ac)

N Rate (lbs/ac)
Distribution of Economic Optimum N Rates

fertilizer = $0.60/lb; corn = $6/bu

from: http://extension.agron.iastate.edu/soilfertility/nrate.aspx

$\sigma \approx 50 \text{ lbs/acre}$
Many sources of variation in N availability and crop needs ➔ generalized recommendations are too simplistic

- Organic amendments (manure, compost, etc.)
- Crop rotations
- Soil type differences
- Soil organic matter contents
- Soil and crop management (tillage, planting date, etc.)
- **Weather:**
  - Temperature
  - Precipitation!

Interactions are complex and nonlinear!
Reasons for Farmer Tendency to Over-Fertilize: Coffee Shop Wisdom on Risk and Risk Perception

• With uncertainty around the optimum N rate, the profit losses from under-fertilizing (yield penalty) are greater than those from over-fertilizing (unnecessary fertilizer expense).

• Under-fertilization results in highly visible leaf yellowing, while over-fertilization is not noticeable.
  – Farmers tend towards the highest rate
  – Consultants cannot afford to under-recommend

• Fertilizer dealers have additional incentives to suggest high rates
Gross Return
Differential Impact of Under and Over-Fertilization due to Nonlinear-Asymmetrical Yield Response to N
(concept after Kachanoski and Fairchild, 1996)

Stochastic Gross Returns:
\[
E[f(Y)] = \left( \int_{-\infty}^{\infty} \left( \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \right) * f(Y) \, dY \right)
\]
Gross Return
stochastic ($\sigma = 50 \text{ lbs/ac}$) and unadjusted (corn=$6.00$/bu)
no consideration for cost of fertilizer
Factoring in Price of Grain and Fertilizer

fertilizer = $0.60/lb; corn = $6/bu

from: http://extension.agron.iastate.edu/soilfertility/nrate.aspx
Maximum Return to N Fertilizer Input
Economic Optimum N Rate
accounting for cost of fertilizer

Accounting for Fertilizer Cost only:

\[ \text{Max} \ \{GR - FC \} \]

Accounting for Fertilizer Cost and Variability (uncertainty):

\[ \text{Max} \left( \int_{-\infty}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \times GR \right) - FC \]

where
GR is the gross return
FC is the fertilizer cost
Return from N Application

unadjusted \((\sigma = 0)\) and stochastic \((\sigma = 50 \text{ lbs/ac})\)

(fertilizer=$0.60/lb; \text{ corn}=$6.00/bu)

- Fertilizer cost only
- Fertilizer cost and \(\sigma = 50 \text{ lbs/ac}\)

Agronomic optimum

EONR

30 lbs/ac

$31
Relative Risk From Erroneous N Fertilizer Application

Grain return and fertilizer cost only

Grain return, fertilizer cost, and $\sigma = 50$ lbs/ac

Risk ($/ac$) vs. N Rate (lbs/ac)
Reasons for Farmer Tendency to Over-Fertilize: Coffee Shop Wisdom on Risk and Risk Perception

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Most farmers ± rationally manage the risks associated with N fertilization based on the imperfect information and tools available to them
Different Fertilizer-Grain Price-Ratios Methods

• Gross return to N application function defined for Floyd silt loam soil in Iowa for $6/bu corn (Graham et al., 2010):
  \[ GR (\$) = 355 + 8.05N - 0.0236 N^2 \]  
  for  \( N \leq 170 \) lbs/ac  
  \[ GR (\$) = 1042 \]  
  for  \( N > 170 \) lbs/ac.

• Stochastic simulations were performed at N rate intervals of 2 lbs/ac using
  – fertilizer:corn price ratios of 0.0033, 0.05, 0.067, 0.083, 0.10, 0.125, 0.15, and 0.20
  – Agronomic N rate uncertainty levels of \( \sigma = 0, 20, 30, 40, \) and 50 lbs/ac.

• Returns to N and needed corrections were determined

Return to N application associated with the economic optimum N rate (EONR)

<table>
<thead>
<tr>
<th>Price Ratio</th>
<th>Return to N at EONR for $6/bu corn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$/ac</td>
</tr>
<tr>
<td>Fertilizer : Corn</td>
<td>no uncertainty</td>
</tr>
<tr>
<td>$1.20 : $6 (0.20)</td>
<td>$497.01</td>
</tr>
<tr>
<td>$0.90 : $6 (0.15)</td>
<td>$541.52</td>
</tr>
<tr>
<td>$0.75 : $6 (0.125)</td>
<td>$564.47</td>
</tr>
<tr>
<td>$0.60 : $6 (0.1)</td>
<td>$587.92</td>
</tr>
<tr>
<td>$0.50 : $6 (0.083)</td>
<td>$603.81</td>
</tr>
<tr>
<td>$0.40 : $6 (0.067)</td>
<td>$619.91</td>
</tr>
<tr>
<td>$0.30 : $6 (0.05)</td>
<td>$636.22</td>
</tr>
<tr>
<td>$0.20 : $6 (0.033)</td>
<td>$652.75</td>
</tr>
</tbody>
</table>

Equation

Profit = \(-935.16PR + 682.4\)

For field corn

Profit = \(-959.8PR + 677.52\)

For sweet corn - FM

Profit = \(-998.23PR + 674.88\)

Profit = \(-1046.7PR + 672.3\)

Profit = \(-1102.4PR + 669.8\)
Return to N at EONR ($/ac)

Combined Price Ratio and Stochastic Corrections based on $6/bu corn

![Graph showing the relationship between Return to N at EONR and Fertilizer:Corn Price Ratio. The graph includes four lines representing different levels of uncertainty and fertilizer application rates.](image-url)
Corrections from Agronomic Optimum N rate to Maximize Returns (lbs N/ac)

<table>
<thead>
<tr>
<th>Price Ratio</th>
<th>Price Ratio Only</th>
<th>Price Ratio + Stochastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer : Corn</td>
<td>σ=0 lbs/ac</td>
<td>σ=20 lbs/ac</td>
</tr>
<tr>
<td>$1.20 : $6 (0.20)</td>
<td>-24</td>
<td>-24</td>
</tr>
<tr>
<td>$0.90 : $6 (0.15)</td>
<td>-18</td>
<td>-16</td>
</tr>
<tr>
<td>$0.75 : $6 (0.125)</td>
<td>-16</td>
<td>-12</td>
</tr>
<tr>
<td>$0.60 : $6 (0.1)</td>
<td>-12</td>
<td>-8</td>
</tr>
<tr>
<td>$0.50 : $6 (0.083)</td>
<td>-10</td>
<td>-4</td>
</tr>
<tr>
<td>$0.40 : $6 (0.067)</td>
<td>-8</td>
<td>0</td>
</tr>
<tr>
<td>$0.30 : $6 (0.05)</td>
<td>-6</td>
<td>+4</td>
</tr>
<tr>
<td>$0.20 : $6 (0.033)</td>
<td>-4</td>
<td>+10</td>
</tr>
</tbody>
</table>

Equation

<table>
<thead>
<tr>
<th>Equation</th>
<th>field corn</th>
<th>sweet corn - FM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corr = 50.55PR^2 – 132.73PR + 0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corr = 529.07PR^2 – 319.94PR + 19.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corr = 787.27PR^2 – 418.57PR + 32.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corr = 1062.80PR^2 – 540.63PR + 50.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corr = 1059.2PR^2 – 587.4PR + 65.41</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Correction from Agronomic Optimum Rate to Obtain Economic Optimum N Rate (lbs/ac of fertilizer)

Combined Price Ratio and Stochastic Corrections
Adapt-N: A Tool for Precision Nitrogen Management in Corn
Provided nitrogen rate recommendations for corn (grain, silage, sweet)
Is server-based ("cloud computing"), and accessible through multiple devices
Its core is the PNM model, built from well-calibrated dynamic simulation models and based on decades of field and modeling research
Uses daily 3x3 mile near-real time weather data (areas East of 100 W Meridian)
Uses NRCS soil database information
High Resolution Climate Data (5 x 5 km) Critical Input to Adapt-N Tool

Precipitation is highly localized and seasonal....

June 2007 Precipitation Iowa
• Simulates crop and soil processes
  – Crop management, rotation, tillage, soil type, OM, organic/inorganic nutrient additions, etc.
• Field or subfield management scale
• Incorporates fertilizer grain-price ratio, and uncertainty corrections
• Provides additional information on:
  – Environmental impact - nitrate leaching and (soon) N₂O losses
  – Additional diagnostic information
  – End-of season situation analysis and “what-if” scenarios
Adapt-N Interface: Manage Locations

Adapt-N: A tool for adaptive nitrogen management in corn production.

Select Location

Modify Location

Set Up New Location

Please identify the region, the season and the location name. You may also identify the group name if you wish.

Northeast 2011 Select Group (optional) Location Name

Please identify the latitude and longitude. You can use the map to do this; if you wish to enter latitude and longitude without using the map, you can click on the clear Lat./Lon. button to remove any information provided by the map.

Latitude (e.g. 42.443) 42.55644705C Longitude (e.g. -76.502) -73.99192535 clear Lat./Lon.

Submit New Location Cancel
Adapt-N Interface: entering Mineral N/Cultivar info

**Adapt-N: A tool for adaptive nitrogen management in corn production.**

<table>
<thead>
<tr>
<th>Season End Date</th>
<th>Adapt-N Home</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Application</th>
<th>Name</th>
<th>lbs N/acre</th>
<th>Placement Depth</th>
<th>Date</th>
<th>Delete Button</th>
<th>Edit Button</th>
</tr>
</thead>
<tbody>
<tr>
<td>starter (fertilizer banded with seed)</td>
<td>monoammonium phosphate</td>
<td>30</td>
<td>2”-4”</td>
<td>n/a</td>
<td>Delete</td>
<td>Edit</td>
</tr>
<tr>
<td>preplant/sidedress</td>
<td>urea</td>
<td>100</td>
<td>2”-4”</td>
<td>04/10/2012</td>
<td>Delete</td>
<td>Edit</td>
</tr>
</tbody>
</table>

You may enter one starter and up to four preplant/sidedress applications. Preplant applications can start as early as 10/1/2011. Select Fertilizer Application.

**Crop Information**

- **Grains:** 110 d crm
- **Planting Date:** 04/15/2012
- **32,500 plants/acre**
- **Grain Cultivars: Expected Yield (bu/acre):** 190 - 210
Adapt-N Interface: entering Soil/Tillage info

**Soil Information**

*Please select a soil texture class that best describes the soil in the field.*

- Canisteo

*Please select the estimated rooting depth.*

- > 38 inches

*Please select the approximate slope (%) of the field.*

- less than 3%

*Was there a soil test?* There was a soil test in the last 3 years.

*If you know the sample depth, please enter it in inches. Otherwise, please enter 6 inches.*

- (inches) 6

- soil organic matter: (%) 3.5

**Tillage System Information**

*Please select the tillage system for this field.*

- Conservation tillage

- 50%
Adapt-N Interface: entering irrigation info

**Adapt-N:** A tool for adaptive nitrogen management in corn production.

**Irrigation:** Please identify irrigation date and the total irrigation amount. Then click on the 'Submit Irrigation' button.
Adapt-N Interface: entering Manure/Sod/Soybean info

When done entering all field info, click ‘Submit’ to run the simulation.
Adapt-N Results Page: Example with need for sidedress N

**Sidedress Nitrogen Recommendation for IA Storm Lake:** 115 lbs N/Acre (101 - 128 lbs N/Acre)

This recommendation is based on an "Expected Yield" entry that is assumed to be the economically optimum yield for this field. The recommended range reflects the uncertainty with post-application fertilizer losses for the remainder of the growing season due to unknown future weather events.

1. Calculation of Sidedress N Rate

   Sidedress N rate estimated by AdaptN = CropNHarvest - CropNCurrent - SoilNCurrent - SoilNpostsidedress - SoybeanNCredit + Losspostsidedress - Correctprofit

   | Term             | Value  
   |------------------|--------
   | CropNHarvest     | 205 lbs N/acre |
   | CropNCurrent     | 65    lbs N/acre |
   | SoilNCurrent     | 28 lbs N/acre    |
   | SoilNpostsidedress| 17 lbs N/acre    |
   | SoybeanNCredit   | 0 lbs N/acre     |
   | Losspostsidedress| 8 lbs N/acre     |
   | Correctprofit    | 0 lbs N/acre     |

**Root Zone Crop Available Water**

*Note that these estimates are for non-irrigated corn production.*

- Current root zone crop available water: 0 inches
- Crop available water at field capacity: 6 inches

- Full Report and Graphs (pdf file)
- Sidedress N Definitions
Email/text alert system for chosen fields

Sidedress Notifications
To setup email and/or text message notification, please complete the Notification and Monitoring sections. You will only receive information about locations for which all Adapt-N input has been provided. Email addresses and cell phone numbers will be kept confidential.

Notification
Select email notification and/or text message notification by checking the appropriate boxes. Please insure that your email address and cell phone information is correct.

☐ Email:

Email Address on record: bnm5@cornell.edu
Update Email

☐ Text Messages:

Cell Phone number on record: missing  Cell Phone Carrier:
Update Cell Phone Information

Monitoring
You will get daily simulation updates for all farm locations that are checked.

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Locations in this Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adapt-NProjects2011</td>
<td>☑ Aurora.NT ☐ Aurora.NT.A ☐ Aurora.NT.G ☐ Aurora.PT</td>
</tr>
</tbody>
</table>
N Recommendation Methodology: deterministic-stochastic mass balance at sidedress

SidedressNrate = CropN_{Harvest} - CropN_{Current} - SoilN_{Current} - SoilN_{postsidedress} - SoybeanN_{credit} + NLoss_{postapplication} - Correct_{profit}

Input: Expected Yield

Near-Real-Time Simulation at Sidedress

Now: simulated & partial fixed credit

Probabilistic simulations
Correction from Agronomic Optimum Rate to Obtain Economic Optimum N Rate
(lbs/ac of fertilizer)

Combined Price Ratio and Stochastic Corrections

[Graph showing the relationship between correction from optimum rate (lbs/ac) and fertilizer:corn price ratio for different scenarios: s=50 lbs/ac, s=40 lbs/ac, s=30 lbs/ac, s=20 lbs/ac, and PR only. The graph indicates the corrections used in Adapt-N.]
Question: Does Adapt-N work?

• **Agronomic:** Does Adapt-N provide an accurate N recommendation at sidedress time?

• **Economic:** Can Adapt-N save growers money in comparison to their current practices?

• **Environmental:** Can Adapt-N decrease N losses?
## Overall Adapt-N Performance 2011-2012, IA and NY

<table>
<thead>
<tr>
<th>Treatment comparison (Adapt-N) – (grower practice)</th>
<th>Iowa</th>
<th>New York</th>
<th>Grand Mean (weighted)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
<td>2012</td>
<td>2011</td>
</tr>
<tr>
<td></td>
<td>(n=9)</td>
<td>(n=19)</td>
<td>(n=14)</td>
</tr>
<tr>
<td>N fertilizer input (lb ac(^{-1}))</td>
<td>-25</td>
<td>-36</td>
<td>-61</td>
</tr>
<tr>
<td>Yield (bu ac(^{-1}))</td>
<td>+2</td>
<td>-1</td>
<td>-3</td>
</tr>
<tr>
<td>Profit ($ ac(^{-1}))</td>
<td>+$26</td>
<td>+$17</td>
<td>+$26</td>
</tr>
<tr>
<td>Trials with greater profit</td>
<td>78%*</td>
<td>74%*</td>
<td>86%*</td>
</tr>
</tbody>
</table>

*Most “misses” were associated with wrong data inputs

**Environmental:**
N losses decreased by 45 kg/ha; N leaching losses by 34 kg/ha (NY, 2011)
Summary

• Variability (uncertainty) in corn N yield response, combined with a nonlinear-asymmetrical corn response relationship implies that the returns to N application are maximized at higher rates than the average economic optimum N rate.
• This explains farmer tendencies for “insurance” fertilizer applications, and their reluctance to reduce N rates for environmental purposes.
• Economic optimum N rates need to be corrected to address underlying uncertainty (farmer’s risk).
• Needed corrections are smaller with lower uncertainty - when N rate recommendations are more precise, but depend on fertilizer and product prices.
• Corrections have been incorporated into Adapt-N tool with varying price ratios for field vs. sweet corn.
Thank you!
Questions?

Adapt-N.cals.cornell.edu

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• USDA-NIFA Special Grant on Computational Agriculture
• Hatch – Smith Lever Funds
• Northern NY Agricultural Development Program
• International Plant Nutrition Institute
• Walton family Foundation
• McKnight Foundation