Nitrogen Management to Increase Fertilizer Efficiency and Reduce Losses

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Photo by K. Olson-Rutz
Goal: Present N management practices that increase fertilizer use efficiency, minimize soil degradation, and decrease losses.

**N concerns:**
- Leaching/runoff
- Volatilization
- Denitrification to N gas
- Soil acidification
- Expense in era of low commodity prices

**Management tools:**
- Soil testing
- N rate
- N source, credits
- Timing
- Placement
- Rotations for N and to ‘catch and release’ N
- Tillage
- Irrigation, but won’t discuss
- Tools and technology, e.g. online N calculators, chlorophyll meters, Nutrient Tracking Tool
N cycles through the soil, plants, and air

Goal is to have N available when needed and reduce losses
Soil tests for N

- Traditional soil test for nitrate-N (nitrate-N), best done in spring to depth determined by region (2 or more feet).
- Illinois N soil test – INST.
  - A measure of soil’s ability to provide N during the growing season.
  - In some areas there is no correlation between INST and economic optimum N rate, check with local Extension
- New tests are being developed to predict N available through mineralization.
Fall soil tests can lead to over or under-fertilized fields

- High N crop residue and/or high O.M.
- High N on shallow or coarse soil
- Mineralization (Residue decomposition)
  - Over winter
  - High Precip
    - N leaching or N$_2$ gas losses
  - Under fertilized
  - Over fertilized

Compare fall with spring a few times to see patterns of loss or gain for given pastures/rotation.
Calculating N rates. Many but not all regions use yield goal in their calculations.

Realistic yield goals

- Use variety selection tools
- Past yields indication of future performance
- Having ability for in-season N application allows conservative yield estimate for pre-plant rate
Because it’s not that simple: N rate calculators

- Example inputs
  - N fertilizer cost, grain price, plump and protein cutoff
  - Yield goal
  - Residual soil N
  - Soil organic matter (SOM)
  - Prior crop
  - N credit from legumes
  - Stubble residue
  - Tillage

- Look for calculators supported by research in your region. Examples

  Montana State University Economic N Rate

  ND Wheat N Calculator [https://www.ndsu.edu/pubweb/soils/wheat/](https://www.ndsu.edu/pubweb/soils/wheat/)

  IA State University Corn N Rate [http://cnrc.agron.iastate.edu/](http://cnrc.agron.iastate.edu/)

See Morris et al. 2018 Agron. J. for a review of N rate calculators for corn
Example N rate adjustments

• Fall vs. spring soil test
• Stubble: small grains stubble high carbon to N (C:N).
  MT example: add 10 lb N/1000 lb stubble up to 40 lb N
• Fallow: assume ½ of stubble has decomposed over previous year when adjusting
• After legume rotation:
  Legumes credit (add) N. Amount depends on region, legume crop, # times grown

<table>
<thead>
<tr>
<th>Montana example</th>
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<tbody>
<tr>
<td>Crop</td>
</tr>
<tr>
<td>Alfalfa</td>
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<tr>
<td>Annual legume</td>
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<tr>
<td>Annual legume</td>
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Soil acidification: a N rate adjustment factor?

- Soil acidification from ammonia based N fertilizer at seeding depth is leading to lower yield → crop failure in traditionally calcareous soils
- MT study found 1 pH drop in 14 yrs at recommended N rates = 0.044 pH drop for every 100 lb N/ac applied.
  - At pH < 6.0, poor legume nodulation
  - At pH < 5.0, aluminum toxicity
- Consider cost of liming in calculation of N rate?

Photo courtesy R. Engel
Variable rate N application (Zone or site specific farming)

- Economic advantage
  - Inconsistent where water limits yield as much or more than N
  - Proven where N, not water, limits yields

- At simplest, divide field into zones of low, med, high productivity = yield potential

Image adapted from IPNI 2012
On to *Sources*
Different N sources have different volatilization and leaching loss potential

<table>
<thead>
<tr>
<th>Source</th>
<th>Volatilization</th>
<th>Leaching</th>
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<tbody>
<tr>
<td><strong>Conventional</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium nitrate, CAN, ammonium sulfate</td>
<td>less</td>
<td>≈</td>
</tr>
<tr>
<td>UAN (solution 28 or 32)</td>
<td>less</td>
<td>≈</td>
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<tr>
<td><strong>Enhanced Efficiency Fertilizers</strong></td>
<td></td>
<td></td>
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<tr>
<td>Urease inhibitors (Agrotain, N-Fixx, Arborite® AG)</td>
<td>less</td>
<td>≈</td>
</tr>
<tr>
<td>Nitrification inhibitors (DCD, N-Source, N-Serve, Instinct)</td>
<td>≈</td>
<td>less</td>
</tr>
<tr>
<td>Combinations (SuperU)</td>
<td>less</td>
<td>less</td>
</tr>
<tr>
<td>Controlled release polymer coated (ESN)</td>
<td>less</td>
<td>less</td>
</tr>
<tr>
<td>Slow release (Nitamin, N-Sure, N-Demand)</td>
<td>≈</td>
<td>less?</td>
</tr>
</tbody>
</table>
High risk conditions for urea and UAN volatilization (Engel et al. 2011, MSU Fertilizer Facts FF59 & 60)

In MT’s cool dry environment, 0-44% of fall/winter broadcast urea N can be lost to volatilization. Worse with:

- Moist soil or heavy dew
- Time between application and incorporation by water or tillage
- High soil pH (>7.0)
- High soil temperature (>50°F) or frozen soil
- Crop residue, perennial thatch or sod
- Low cation exchange capacity soil (sandy)
- Poorly buffered soils (low soil organic matter, low bicarbonate content) because urea increases pH around prill, increasing loss.

The risk of loss increases as the number of high risk conditions increase, with soil moisture and incorporation likely being the most important.
Urea requires 2” incorporation with water or tillage to protect from volatilization

Surface soil was pre-moistened

Echo, Oregon
Soil Temp = 46°F
Holcomb et al. 2011

$R^2 = 0.92$
Effect of N source on volatilization

Total 110-day loss (% of ON)

- Urea
- PCU
- U+NBPT
- U+DCD

2013
2014

Tian et al 2015, LA

100 lb N/ac side-dress on reduced till cotton
No till corn yields increase when surface applied UAN and urea are treated with NBPT or polymer coating (PC)

Liu et al., 2019, TN, notill corn averaged across N rates of 110 to 180 lb N/ac applied at seeding
Frequency of corn yield response between pre-plant PCU (ESN®) and conventional N at equal rates (US corn-belt (2000-2004))

Blaylock et al, 2006
Slow- and controlled-release

- Benefit depends on climate/weather
- Consider in areas with high leaching or denitrification potential
- Release of polymer coated urea depends on warmth and moisture, can be too slow with late winter/early-spring application in cool/dry environments
- If fall application to reduce spring workload is important, then extra cost might be worth it
- May benefit protein more than yield, and protect water quality
Nitrification inhibitors (e.g. DCD): delay ammonia (NH$_4^+$) to nitrate (NO$_3^-$) conversion

- Reduces leaching and N$_2$ gas loss
- Potential benefit with fall-banded urea where:
  - high precip with leaching in sandy soils
  - denitrification (nitrate \( \rightarrow \) N$_2$ gas) in water logged/clay soils
- Benefits less likely in dry or well drained soils
- DCD sprayed before fall plow-down can slow decomposition and leaching loss (Francis 1995)
Instinct II® (nitrification inhibitor) increased winter wheat grain yield under irrigation but not dryland

Scherder et al., 2015, inland Pacific NW
UAN sidedress dribble stream bar, urea preplant incorporated
On to *Timing*
Time application to supply when needed and protect from losses

N source

• Readily available [urea (46–0–0), urea ammonium nitrate (28–0–0)]
  ▪ shortly before seeding up to mid-tillering

• Slowly available (manure, slow-release N)
  ▪ take time to become available
  ▪ apply before needed – e.g., fall in semi-arid conditions
Uptake depends on growth stage NOT calendar day. N available before stem elongation goes to wheat yield, N after goes to grain protein.

For assorted crop uptake curves see http://landresources.montana.edu/soilfertility/nutuptake.html
In-season split application allows N rate adjustment based on:

- The crop’s potential need
- The soil’s ability to supply N
- These depend on the growing season which is why there is no definite clear benefit on yield of split (or side-dress) app over preplant.

Bushong et al, 2016, OK, UAN preplant and between V8-V12
Split-application increases options and maybe net returns

Use regionally available tools to decide if late-season N or not. Ex. flag leaf N, pre-sidedress N test, chlorophyll readings

8 lb N/ac applied with seed, total fertilizer 67 lb N/ac

Graham and Stockton 2019, SD, dryland winter wheat

<table>
<thead>
<tr>
<th>Yield bu/ac</th>
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<tbody>
<tr>
<td>56.5</td>
</tr>
<tr>
<td>54.1</td>
</tr>
<tr>
<td>56.1</td>
</tr>
<tr>
<td>56.5</td>
</tr>
<tr>
<td>55.9</td>
</tr>
</tbody>
</table>
On to *Crop rotations to catch residual N* and *reduce loss from system*
Deep rooted crops dig deep for N and help keep nitrate out of groundwater

6-yr average, Sidney, MT, MSU Fertilizer Fact 9
Poor match between uptake timing and availability
Reduce the ‘brown gap’ by catching the losses with overwinter cover crops.

<table>
<thead>
<tr>
<th>4-yr total N lost in drainage</th>
<th>lb nitrate-N/ac</th>
</tr>
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<tbody>
<tr>
<td>Corn-soy notill</td>
<td>90</td>
</tr>
<tr>
<td>Corn-soy notill + winter rye cover</td>
<td>29</td>
</tr>
<tr>
<td>Corn-soy fall chisel plow</td>
<td>78</td>
</tr>
</tbody>
</table>

In brown gap, N by soil greater than crop N uptake

Kaspar et al, 2017 USDA-ARS National Conference on Crop and Soil Health
20-yr cropping systems with tillage and fallow have greatest estimated N loss

Sainju et al. 2009, Culbertson, MT

N loss = Initial soil N + fertilizer N + surface residue N - grain N - final soil N

NT notill; SpT spring till; FSpT fall spring till; CW continuous wheat; WF wheat fallow
Tillage

- Increases mineralization rate, creates a flush of N. Have a crop in place to ‘catch’ it.

- Delay until late in fall or spring to reduce leaching loss (Francis et al. 1995, Australia)

No-till

- Moderates temperature
- Increases water infiltration and storage
The % change of nitrate runoff and leaching with no-till compared to tilled

With 95% confidence intervals, (Daryanto et al. 2017, review paper)

- Pattern holds for both organic and inorganic fertilizers
- Runoff increases with NT after 10 yrs duration
- Leaching on NT is greater than on CT in wheat and corn, but the same on soy

Adjust management to reduce NT leaching.
- Reduce N rates where possible
- Cover crop
- Split N applications
- Light tillage every 10 yrs to alter the causes of nitrate losses (e.g. disrupt macropores that enhance leaching).
Judith Basin Nitrogen Project

Farmer’s used alternative vs ‘standard’ practices for 2 growing seasons.

Pea grain-wheat leached less one year than fallow-wheat, equal NR. Leaching no diff between rotations in 2nd year, NR greater with pea-wheat.

John et al. 2017
Nitrate Source:
Organic matter mineralization mainly during fallow

Mineralization of organic matter is 30-60 lb/acre in the top 6 inches; this is on par with annual fertilizer rates in this MT semi-arid region.

Figure from Newsletter #2 in December 2014

Jones unpub. data
Continuous cropping leaves less nitrate in soil to leach

37 years of each dryland cropping system with spring wheat

Campbell et al, 2006
Swift Current, SK
N management factors to decrease N leaching

• Apply N based on spring soil test
• Split N application to match plant needs
• Avoid fall application on shallow and/or coarse soils
• Consider applying less N in areas that yield less or have shallow soils (variable rate application)
• Use an enhanced efficiency fertilizer to reduce leaching (and denitrification) losses
On to

_Crop Rotations to Supply N_
N from legumes

- Legume cover crops release more N more quickly than legume grain (pulse).
- N benefit depends on the legume species, how long grown (cover crop vs grain), how often grown, growing and decomposing conditions.

- Legumes should be 50% of cover crop to provide plant available N (PAN), especially if terminated late.

Sullivan and Andrews, 2012, OR
Plant available N from plant residue

Depends on C:N.

- Leafy green lower in C:N = more N available to next crop
- Mature plant higher in C:N, at > 24:1 microbes tie up N

Balance C:N by:

- Termination timing
- Mix species planting
- Sequential high N, low N rotations
- Look for regional PAN calculators
Legumes are the ultimate slow release N, after the initial burst of N release, especially when grown to grain.

A pulse rotation can still provide N for grain planted three years after the pulse crop.

Lupwayi and Soon 2015, AB, 10.7” growing season precip
Diverse rotations generally have greater N fertilizer recovery, when legume N credit is included in N fertilizer rates.

Rick et al. 2015, MT dryland-yrs no till, avg. from years 10 to 13 of rotations.

Bar chart showing mean N fertilizer recovery (%):
- Clover Ccrop (a)
- Flax S Wheat (b)
- Pea grain W Wheat (bc)
- Pea grain S Wheat (cd)
- S Wheat W Wheat (d)

Legend:
- W Wheat
- S Wheat
- Lentil
- Canola
- Safflower
- Corn
- Pea grain
Pea grown for grain more profitable than as hay or cover

Rotation at full N | pH
---|---
Initial | 7.4
After 14 yrs | 6.2b
  - WW full N
  - Pea grain

Net $/acre summed 2013 to 2016

Cropping system:
- TF
- NTF
- WW
- PgW
- PhW
- PcW
- CRP-PgW

Miller et al. 2017, MSU Fertilizer eFact # 72
Summary

• A combination of management changes is likely needed to substantially increase NUE
• Manage N with the N‐cycle in mind to supply N when needed, reduce N losses, and protect soil, water, and air quality and client’s pocket book
• Each growing region will have unique best management practices to increase NUE – look for local information
• Research can’t test all possible conditions – do strip trials with willing producers
QUESTIONS?

This presentation and additional information on soil fertility topics are available at
http://landresources.montana.edu/soilfertility

Photo by Andrew John